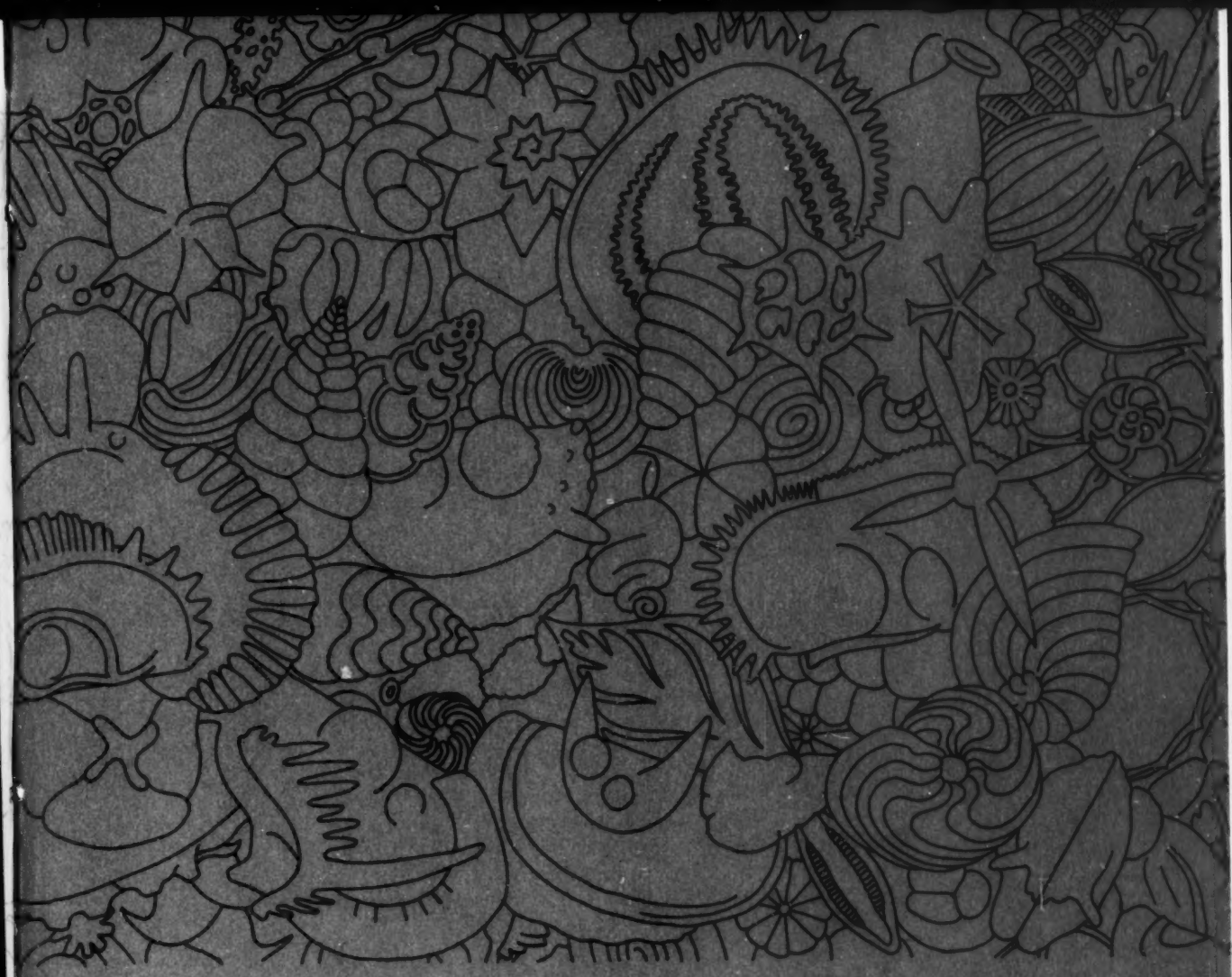

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ABSTRACT: *The planktonic foraminifera of northwestern Peru are discussed with regard to their value as index fossils. Formation tables, an index map of northwestern Peru, and a range chart of Peruvian planktonic foraminifera are included.*

Planktonic index foraminifera of northwestern Peru

LAWRENCE WEISS
International Petroleum Company, Ltd.
Talara, Peru

INTRODUCTION

Sedimentary deposits of northwestern Peru contain planktonic foraminifera indicative of ages ranging from Cretaceous to Miocene. The faunas are allied to those of the Caribbean region. In northern Peru, calcareous foraminifera are generally leached from outcrops, leaving only a residue of arenaceous forms. Hence all of the Peruvian data here presented were obtained from wells drilled by the International Petroleum Company, Ltd., in the La Brea—Pariñas area, in the Chira Valley, and in the Sechura Desert (see text-fig. 1).

Acknowledgment is made to the management of the International Petroleum Company, Ltd., for permission to publish this paper. The author also wishes to express his gratitude to R. M. Stainforth and A. G. Fischer for their many valuable suggestions and criticisms.

SIGNIFICANT GUIDE FOSSILS

Cretaceous

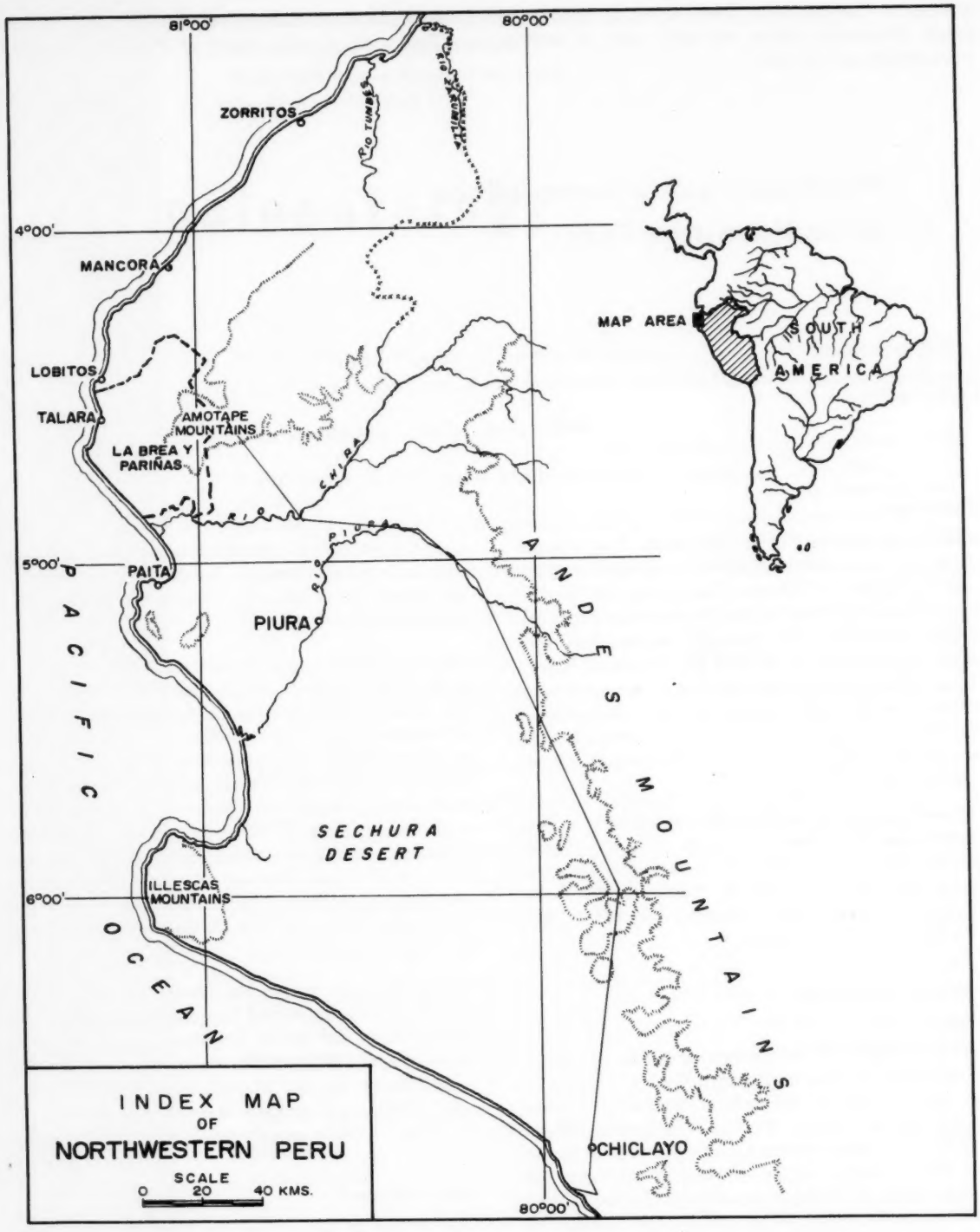
The thick Middle to Late Cretaceous section of clastics deposited in the Peruvian geosyncline (see Table I) has yielded little in the way of diagnostic foraminiferal faunas, except for the Campanian—Maestrichtian Redondo—Monte Grande formations of the La Brea—Pariñas region. Faunal assemblages of minute forms of *Globigerina* and *Gümbelina*, as well as *Ovalveolina*, were recognized in thin sections of cores from the Albian Muerto formation and succeeding beds believed to range in age up to Lower Senonian, but attempts to establish a vertical faunal succession have failed. This may be due to long range of the species, or to difficulties in distinguishing species in thin section.

The presence of Upper Cretaceous in beds other than those of the La Brea—Pariñas area was indicated by the occurrence of benthonic foraminifera, including *Allomorphina* sp., *Chilostomella* sp., and *Bathysiphon* sp., in association with *Inoceramus* prisms in the Copa Sombrero formation. Recently, a core from these beds yielded free, identifiable specimens of planktonic foraminifera, namely, *Globigerina cretacea*, *Gümbelina globulosa*, and *Globotruncana lapparenti* subspp. The forms of *Globotruncana* are especially significant as stratigraphic markers (Bolli, 1951), and place this Cretaceous section, at least, in the Senonian stage of the Upper Cretaceous.

Rugoglobigerina rugosa has been observed on rare occasions in the uppermost Cretaceous Redondo shale, Petacas shale, and Monte Grande sandstone in northwestern Peru. It is considered to be a good index foraminiferan for the Maestrichtian stage (Bronnimann, 1952), and confirms the age determination of the Monte Grande megafauna (Olsson, 1934).

Danian — Paleocene

Only a few of the Danian to Paleocene planktonic foraminifera are valuable as horizon markers in Peru. Assemblages of small, variable, usually poorly pre-



TEXT-FIGURE 1

FORMATION TABLES OF NORTHERN PERU

TABLE I

CRETACEOUS–EOCENE

			NORTHWEST PERU	
CENOZOIC	TERTIARY	UPPER EOCENE	VERDUN-CHIRA GROUP	CONE HILL MIRADOR CHIRA VERDUN
			TALARA-POZO GROUP	POZO TALARA SANDSTONE TALARA SHALE
		MIDDLE EOCENE		
		LOWER EOCENE	SALINA-CHACRA GROUP	CABO BLANCO CHACRA PARIÑAS PALE GREDA SALINA
		PALEOCENE: MIDWAY		
		PALEOCENE: DANIAN	MAL PASO GROUP	BALCONES MESA
MESOZOIC	CRETACEOUS	MAESTRICHTIAN		MONTE GRANDE / PETACAS REDONDO TABLONES
		CAMPANIAN		
		TURONIAN-CENOMANIAN		COPA SOMBRERO
		ALBIAN		MUERTO PANANGA
PALEOZOIC		PENNSYLVANIAN AND OLDER		PALEOZOIC METAMORPHICS

TABLE II

OLIGO–MIOCENE

		SECHURA DESERT	ZORRITOS AREA
MIOCENE	MID.	UNNAMED	CARDALITOS
	LOW.	MONTERA	ZORRITOS
OLIGOCENE	UPP.	UNDIFFERENTIATED	? HEATH
	MID.		"MANCORA"

Unconformity

Local Unconformity

served globigerinids of the *Globigerina pseudotriloba—eocaenica—triloculinoides* type occur in the Balcones shale as well as in the overlying Salina, Pale Greda, and Chacra formations (see Table I). At the present writing, no planktonic foraminifera have been noted to supplement the benthonic *Rzehakina epigona—Marssonella oxycona* fauna of the Balcones shale as regional Danian markers. On the other hand, the *Globigerina* group mentioned above is augmented in the Pale Greda formation (Midway, Montian) by *Globorotalia crassata aequa* and *Globorotalia wilcoxensis*. In Cuba these are Paleocene index fossils (Cushman and Bermudez, 1949), and *Globorotalia crassata aequa* is similarly valuable in Trinidad (Bolli, 1952).

Eocene

Planktonic foraminifera are well represented in the Eocene sediments of northern Peru. No specific index forms have been recognized in the Lower Eocene, but most of the long-ranging Paleocene species of *Globigerina* extend into the Lower Eocene, and very rare specimens of *Globorotalia* cf. *membranacea* have been observed in the Lower Eocene Chacra shale. The lower part of the Talara formation (see Table I) contains *Globigerina wilsoni bolivariana* and *Hastigerinella colombiana*. Both of these are important Middle Eocene index fossils in Colombia (Petters, 1954), and thus support the Middle Eocene dating of the lower Talara formation on the basis of the *Helicolepidina—Discocyclina* assemblage in the sandy facies. The Verdun sandstone has been dated as Upper Eocene, based on the occurrence of *Lepidocyclina (Lepidocyclina)* and *Helicostegina*, but lacks planktonic forms. The overlying Chira shale, however, contains such regional Upper Eocene planktonic foraminifera as *Hantkenina primitiva, Globigerina mexicana, Globigerina topilensis,* and *Gümbelina venezuelana*.

The Mirador and Cone Hill formations constitute the topmost Eocene beds of the La Brea—Pariñas region. The Mirador and Cone Hill microfaunal assemblages are best known from International Petroleum Company's well 3575. *Hantkenina primitiva*, the rounded, inflated form of *Globigerina triloculinoides*, and *Globigerina wilsoni* extend from the Chira formation to the top of the Cone Hill. *Hastigerinella eocanica* ranges into the Mirador formation in well 3575, but was not observed in the Cone Hill shale. A few specimens of *Globigerina venezuelana* were noted at the top of the Cone Hill formation and indicate, on a regional scale, the approach of the Oligocene.

Oligocene

The foraminiferal faunules of the northwest Peruvian Oligo-Miocene deposits in the Mancora—Zorritos area and in the Sechura Desert (see Table II) are mainly facies-controlled benthonic assemblages. Similar genera and species are found at various horizons in the Oligo-Miocene formations. With the limited information available, it is difficult to determine which species are of the long-ranging facies type and which might be useful as index fossils because of gradual evolutionary development. *Siphogenerina smithi*, and siphogenerinids of the *Siphogenerina transversa—reedi* and *Siphogenerina multicostata—seriata* groups (fairly good Middle to Upper Oligocene markers in Ecuador) have been found in Peru only in beds considered to be Oligocene, but elsewhere some of the species range into the Lower Miocene. Recent wildcat drilling in the Sechura Desert has substantiated the Oligocene age determination for the *Siphogenerina* zone with the regional late Middle and Upper Oligocene planktonic foraminifera *Globorotalia barissanensis* and *Globorotalia fohsi*.

Occasional specimens of *Globigerina dissimilis* have been observed in the Heath shale at Zorritos, but no specimens of *Globorotalia barissanensis* or *Globorotalia fohsi* have ever been noted. Conversely, *Globorotalia barissanensis* is common in the upper part of the undifferentiated Oligocene sediments in the Sechura Desert, and *Globigerina dissimilis* has not been recorded from any of the Sechura Desert Oligocene deposits. In Ecuador, *Globigerina dissimilis* does not range above the Middle Oligocene, and *Globorotalia barissanensis* is an excellent late Middle and Upper Oligocene marker (Stainforth, 1948). This suggests that the Zorritos Heath shale is somewhat older than the shale beds in the upper part of the Sechura undifferentiated Oligocene. Perhaps the sandy Oligocene facies above the Heath shale at Zorritos is the time equivalent of the Oligocene shale with *Globorotalia barissanensis* in the Sechura Desert.

The planktonic foraminiferal assemblage indicative of the Lower Oligocene to early Middle Oligocene in Ecuador, *Globigerina dissimilis—Globigerina ciperoensis* (cf. *concinna*) (Stainforth, 1948), has not yet been observed in Peru.

Miocene

Many planktonic foraminifera range throughout the Oligo-Miocene of Peru, but *Globorotalia menardii* and *Sphaeroidinella dehiscens* are found restricted to the shales overlying the Montera formation (see Table II), a unit dated as Lower Miocene by means of mollusks

(Olsson, 1932). These two species are recognized elsewhere as Lower to Middle Miocene markers. The orbulines, including *Orbulina suturalis, Orbulina bilobata,* and *Orbulina universa,* range from Upper Oligocene to Lower Miocene in the Caribbean area, but to date this group has only been noted in the Peruvian Miocene. Upper Miocene foraminifera, such as *Globorotalia menardii multicamerata* and *Pulleniatina obliquiloculata,* are still unknown from the sediments of northern Peru.

NOTES ON INDIVIDUAL SPECIES

For the sake of convenience, the following is a systematic list of species discussed in this paper. Below, the individual species are briefly described in order of decreasing geologic age (see range chart).

Order FORAMINIFERA

Family HETEROHELICIDAE

Subfamily GÜMBELININAE

Genus GÜMBELINA EGGER, 1900

Gümbelina globulosa (p. 307)
Gümbelina cf. *trinitatensis* (p. 307)
Gümbelina venezuelana (p. 310)

Family GLOBIGERINIDAE

Subfamily GLOBIGERININAE

Genus GLOBIGERINA d'Orbigny, 1826

Globigerina altispira (p. 310)
Globigerina aff. *bulloides* (p. 311)
Globigerina cretacea (p. 307)
Globigerina dissimilis (p. 310)
Globigerina eocaenica (p. 308)
Globigerina mexicana (p. 309)
Globigerina pseudotriloba (p. 308)
Globigerina sp. (p. 311)
Globigerina stonei (p. 308)
Globigerina topilensis (p. 309)
Globigerina trilocularis (p. 308)
Globigerina triloculinoides (p. 308)
Globigerina venezuelana (p. 310)
Globigerina wilsoni (p. 309)
Globigerina wilsoni bolivariana (p. 309)

Genus RUGOGLOBIGERINA Bronnimann, 1952

Rugoglobigerina rugosa (p. 307)

Genus GLOBIGERINOIDES Cushman, 1927

Globigerinoides conglobatus (p. 311)
Globigerinoides ruber (p. 312)
Globigerinoides sacculifer (p. 311)
Globigerinoides sp. indet. (p. 312)
Globigerinoides triloba (p. 311)

Genus GLOBIGERINELLA Cushman, 1927

Globigerinella aequilateralis (p. 311)

Genus HASTIGERINELLA Cushman, 1927

Hastigerinella colombiana (p. 309)
Hastigerinella eocanica (p. 309)

Subfamily ORBULININAE

Genus ORBULINA d'Orbigny, 1839

Orbulina bilobata (p. 312)
Orbulina suturalis (p. 312)
Orbulina universa (p. 313)

Subfamily PULLENIATININAE

Genus SPHAEROIDINELLA Cushman, 1927

Sphaeroidinella dehiscens (p. 313)

Family HANTKENINIDAE

Genus HANTKENINA Cushman, 1925

Hantkenina primitiva (p. 309)

Family GLOBOROTALIIDAE

Genus GLOBOTRUNCANA Cushman, 1927

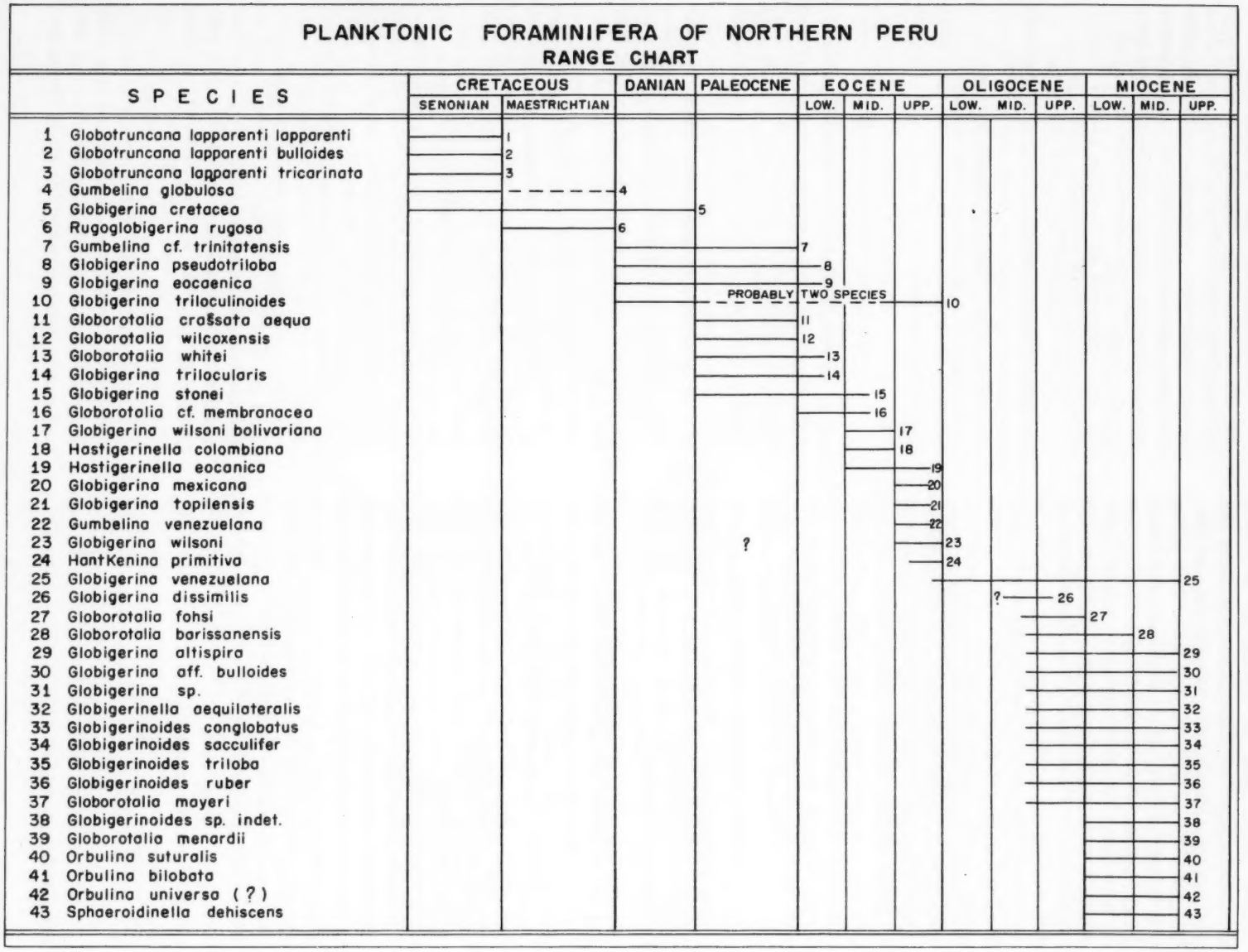
Globotruncana lapparenti bulloides (p. 307)
Globotruncana lapparenti lapparenti (p. 307)
Globotruncana lapparenti tricarinata (p. 307)

Genus GLOBOROTALIA Cushman, 1927

Globorotalia barissanensis (p. 310)
Globorotalia crassata aequa (p. 308)
Globorotalia fohsi (p. 310)
Globorotalia mayeri (p. 312)
Globorotalia cf. *membranacea* (p. 309)
Globorotalia menardii (p. 312)
Globorotalia whitei (p. 308)
Globorotalia wilcoxensis (p. 308)

PLANKTONIC FORAMINIFERA OF NORTHERN PERU

RANGE CHART



Globotruncana lapparenti lapparenti Brotzen
Plate 1, figures 1-2

Rosalina linnei d'Orbigny, type 1, DE LAPPARENT, 1918, Mém. Carte Géol. France, p. 4, tfs. 1a, c.
Globotruncana lapparenti lapparenti Brotzen. – BOLLI, 1945, Eclogae Geol. Helv., vol. 37 (1944), no. 2, p. 230, tf. 1, nos. 15, 16; pl. 9, fig. 11.
Globotruncana canaliculata (Reuss). – CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper 206, p. 149, pl. 61, fig. 17a-c.

Bolli (1951) has very adequately discussed the value of the species of *Globotruncana* as index markers in Trinidad. His chart depicting comparative axial sections of double-keeled forms is a useful guide for identifying thin sections of the various species.

Globotruncana lapparenti lapparenti is characterized in axial section by its low-arched dorsal side and comparatively flat ventral.

Occurrence in Peru: Rare in the Redondo and Copa Sombrero formations.

Globotruncana lapparenti tricarinata (Quereau)
Plate 1, figures 6-7

Pulvinulina tricarinata QUEREAU, 1893, Beitr. Geol. Karte Schweiz, no. 33, pl. 5, fig. 3a.
Rosalina linnei d'Orbigny, type 2, DE LAPPARENT, 1918, Mém. Carte Géol. France, p. 4, tfs. 1b, d, e, f; p. 5, tfs. 2d, n.
Globotruncana lapparenti tricarinata (Quereau). – BOLLI, 1945, Eclogae Geol. Helv., vol. 37 (1944), no. 2, pp. 232-233, tf. 1, nos. 19-20; pl. 9, fig. 13.

The distinctive feature of *Globotruncana lapparenti tricarinata* is the third "keel" formed by the raised rim of shell material around the umbilicus.

Occurrence in Peru: At the present time, this subspecies has been noted in a Cretaceous shale section of only one well, and is believed to indicate a Senonian age.

Globotruncana lapparenti bulloides Vogler
Plate 1, figures 3-5

Rosalina linnei d'Orbigny, type 3, DE LAPPARENT, 1918, Mém. Carte Géol. France, p. 4, tf. 1h; p. 5, tfs. 2a, e, g.
Globotruncana linnei bulloides VOGLER, 1941, Palaeontographica, Supplement, vol. 4, pl. 23, figs. 32-39.
Globotruncana lapparenti bulloides Vogler. – BOLLI, 1945, Eclogae Geol. Helv., vol. 37 (1944), no. 2, pp. 231-232, tf. 1, nos. 17-18; pl. 9, fig. 12.

This subspecies differs from *Globotruncana lapparenti tricarinata* in having a flatter dorsal spire and a lower, more gently rounded, ventral aspect.

Occurrence in Peru: Identical with that of *Globotruncana lapparenti lapparenti.*

Gümbelina globulosa (Ehrenberg)
Plate 1, figure 8

Textilaria globulosa EHRENBERG, 1854, K. preuss. Akad. Wiss. Berlin, Abh., p. 135, pl. 4, fig. 4b.

This is a small species with globular chambers increasing fairly rapidly in size, and a lunate aperture at the base of the last septal face. In well preserved specimens the pores are arranged in very faint lines. The species is reported from the Campanian and Maestrichtian in the Gulf Coast region, from the Coniacian to the top of the Danian in the Pyrenees, and from the Midway of Mexico (Hamilton, 1953).

Occurrence in Peru: Common in thin sections and rare as free specimens from the Muerto, Copa Sombrero, and Redondo formations, thus ranging through sediments of Albian to Senonian age, and very probably into the Maestrichtian.

Globigerina cretacea d'Orbigny
Plate 1, figure 10

Globigerina cretacea D'ORBIGNY, 1840, Mém. Soc. Géol. France, ser. 1, vol. 4, p. 34, pl. 3, figs. 12-14.

This form is characterized by five to six globular chambers. The literature contains many records, ranging from the Upper Cretaceous through the Paleocene.

Occurrence in Peru: This species ranges from the Copa Sombrero formation into the Balcones shale.

Rugoglobigerina rugosa (Plummer)
Plate 1, figure 9

Globigerina rugosa PLUMMER, 1927, Univ. Texas Bull. 2644, p. 38, pl. 2, fig. 10.

A closely coiled species with five distinctly globular, rugose chambers in the adult form. The holotype of this species is from the upper Navarro (Maestrichtian) of Texas. Bronnimann (1952) observed related subspecies *(Rugoglobigerina rugosa pennyi* and *Rugoglobigerina rugosa rotundata)* in the Maestrichtian of Trinidad.

Occurrence in Peru: Rare but diagnostic for the Redondo and Monte Grande formations of northern Peru.

Gümbelina cf. **G. trinitatensis** Cushman and Renz
Plate 1, figure 14

?Gümbelina trinitatensis CUSHMAN AND RENZ, 1942, Cushman Lab. Foram. Res., Contr., vol. 18, p. 8, pl. 2, fig. 8a-b.

Occurrence in Peru: Poorly preserved forms in the Balcones, Salina, and Pale Greda formations seem to be referable to this species.

Globigerina pseudotriloba White
Plate 1, figures 11-13

Globigerina pseudotriloba WHITE, 1928, Jour. Pal. vol. 2, p. 194, pl. 27, fig. 17.

This is a small, globular, three-chambered species.

Occurrence in Peru: A long-ranging form, fairly common in the Balcones, Salina, Pale Greda, and Chacra formations.

Globigerina eocaenica Terquem
Plate 1, figures 15-17

Globigerina eocaenica TERQUEM, 1882, Mém. Soc. Géol. France, ser. 3, vol. 2, no. 3, p. 86, pl. 9, fig. 4.

This species is differentiated from *Globigerina pseudotriloba* by its more compressed test and less lobulate periphery.

Occurrence in Peru: Same range as *Globigerina pseudotriloba.*

Globigerina triloculinoides Plummer
Plate 1, figures 18-21

For references and figures see Cushman, 1951, U. S. Geol. Survey, Prof. Paper 232, p. 60, pl. 17, figs. 10-11.

This is a small species with three and one-half globular, dorsally rounded chambers, and rarely with the apertural flap figured by Plummer (1927, p. 134, pl. 8, fig. 10).

Occurrence in Peru: Another of the long-ranging (Balcones through Cone Hill) Peruvian species of *Globigerina.* There are very likely two species included in *Globigerina triloculinoides* as used here. The small, quadrate specimens (see figs. 18-19) are prevalent in the Pale Greda formation. The larger, inflated, trigonally rounded form common in the Chira and Cone Hill formations (see figs. 20-21) is similar to the specimen figured by Beck (1943) from the Eocene Cowlitz formation of Washington, and by Stainforth (1948) from the Upper Eocene—basal Oligocene of Ecuador.

Globorotalia crassata aequa Cushman and Renz
Plate 1, figures 26-28

Globorotalia crassata (Cushman) var. *aequa* CUSHMAN AND RENZ, 1942, Cushman Lab. Foram. Res., Contr., vol. 18, p. 12, pl. 3, fig. 3. – CUSHMAN AND BERMUDEZ, 1949, ibid., vol. 25, p. 37, pl. 7, figs. 7-9.

An easily distinguishable subspecies with three and one-half chambers, which taper ventrally, and a sharp dorsal keel. As mentioned earlier in the text, this species is recognized as a good Paleocene marker in Cuba (Cushman and Bermudez, 1949) and Trinidad (Bolli, 1952).

Occurrence in Peru: An excellent index fossil which is fairly common in, and restricted to, the Salina and Pale Greda formations.

Globorotalia wilcoxensis Cushman and Ponton
Plate 1, figures 24-25

Globorotalia wilcoxensis CUSHMAN AND PONTON, 1932, Cushman Lab. Foram. Res., Contr., vol. 8, p. 71, pl. 9, fig. 10a-c. – CUSHMAN AND BERMUDEZ, 1949, ibid., vol. 25, p. 39, pl. 7, figs. 16-18.

The characteristic feature of this form with four to four and one-half chambers is the angular periphery of the last-formed chamber.

Occurrence in Peru: Rare in Peru, with the same range as *Globorotalia crassata aequa.*

Globorotalia whitei Weiss
Plate 1, figures 29-30

Globorotalia whitei WEISS, 1955, Jour. Pal., vol. 29, no. 1, p. 18, pl. 6, figs. 1-3.
Globigerina crassaformis Galloway and Wissler. – WHITE, 1928, Jour. Pal., vol. 2, p. 193, pl. 27, fig. 14.
Globorotalia crassaformis (Galloway and Wissler). – NUTTALL, 1935, Jour. Pal., vol. 9, p. 130, pl. 15, figs. 21, 29.

A small species with a bluntly angular periphery, shallow umbilicus, and four appressed, ventrally tapering chambers, the initial three of the last whorl subequal in size and shape.

Occurrence in Peru: Rare in the Salina, Pale Greda, and Chacra formations of northern Peru.

Globigerina trilocularis d'Orbigny
Plate 1, figures 22-23

Globigerina trilocularis d'Orbigny. – BANDY, 1944, Jour. Pal., vol. 18, p. 376, pl. 62, fig. 7a-b.

This is a fairly high-spired, globular-chambered species.

Occurrence in Peru: Rare, with the same Paleocene—Lower Eocene range as *Globorotalia whitei.*

Globigerina stonei Weiss
Plate 2, figures 1-3

Globigerina stonei WEISS, 1955, Jour. Pal., vol. 29, p. 18, pl. 5, figs. 16-21.
Globigerina cf. *G. pseudobulloides* Plummer. – CUSHMAN AND STONE, 1949, Cushman Lab. Foram. Res., Contr., vol. 25, p. 57, pl. 10, fig. 15.

A small, four-chambered species with a slight ventral taper. The dorsal side is flattened and the ventral convex with a large, open umbilicus.

Occurrence in Peru: A long-ranging species, fairly common in the Salina to lower Talara formations.

Globorotalia cf. **membranacea** (Ehrenberg)
Plate 2, figures 4-5

Globorotalia cf. *membranacea* (Ehrenberg). – CUSHMAN AND STONE, 1949, Cushman Lab. Foram. Res., Contr., vol. 25, p. 57, pl. 10, fig. 16.

Occurrence in Peru: Very rare specimens, questionably referable to this species, have been reported from the Chacra and lower Talara formations.

Globigerina wilsoni bolivariana Petters
Plate 2, figures 6-8

Globigerina wilsoni bolivariana PETTERS, 1954, Cushman Found. Foram. Res., Contr., vol. 5, p. 39, pl. 8, fig. 9.

This is a large, roundly robust, almost planispiral subspecies from the Middle Eocene of Colombia (Petters, 1954). Some of the Peruvian specimens have a tendency toward *Globigerinella*-like uncoiling.

Occurrence in Peru: Restricted to Middle Eocene (lower Talara) shales.

Hastigerinella colombiana Petters
Plate 2, figures 9-10

Hastigerinella colombiana PETTERS, 1954, Cushman Found. Foram. Res., Contr., vol. 5, p. 40, pl. 8, fig. 10.

A middle Eocene Colombian species (Petters, 1954) characterized by its elongated, flattened, rapidly widening chambers.

Occurrence in Peru: This is another good Middle Eocene lower Talara index foraminiferan, usually identified on the basis of loose individual chambers.

Hastigerinella eocanica Nuttall
Plate 2, figures 11-13

Hastigerinella eocanica NUTTALL, 1928, Jour. Pal., vol. 2, p. 376, pl. 50, figs. 9-11.

This species is widely known from the Middle and Upper Eocene of the Caribbean province (Stainforth, 1948).

Occurrence in Peru: Although complete tests are extremely rare, single chambers are common in the Talara, Chira and Mirador formations of northern Peru.

Globigerina wilsoni Cole
Plate 2, figures 22-23

Globigerina wilsoni COLE, 1927, Bull. Amer. Pal., vol. 14, no. 51, p. 34, pl. 4, figs. 8-9.

The holotype is from the Eocene of Mexico. Stainforth (1948) has reported this species from the late Middle and Upper Eocene and the Lower Oligocene of Ecuador. The typical form is smaller, less rotund, and shows more of the penultimate whorl than the Colombian subspecies *bolivariana*.

Occurrence in Peru: Typical specimens, occasionally with an apertural lip, have been observed only in the Chira to Cone Hill (Upper Eocene) shales. Very rare specimens in the Peruvian Paleocene have been compared with this species, but the aperture of the Paleocene forms is more ventrally located than that of the Upper Eocene specimens. This is often the case in immature forms of *Globigerina wilsoni*, and therefore the rare Paleocene records may represent either young specimens of *Globigerina wilsoni* or a different globigerinid species.

Hantkenina primitiva Cushman and Jarvis
Plate 2, figure 14

Hantkenina alabamensis Cushman var. *primitiva* CUSHMAN AND JARVIS, 1929, Cushman Lab. Foram. Res., Contr., vol. 5, p. 16, pl. 3, figs. 2-3.

The spinose, inflated, typically hantkenine chambers occur only in the mature adult. The early chambers are globular and usually without spines.

Occurrence in Peru: Very rare specimens are restricted to the Upper Eocene Chira and Cone Hill formations.

Globigerina mexicana Cushman
Plate 2, figure 15

Globigerina mexicana CUSHMAN, 1925, Cushman Lab. Foram. Res., Contr., vol. 1, p. 6, pl. 1, fig. 8.

A quasi-spherical species which appears to be a worldwide Eocene horizon marker, particularly for the Middle and Upper Eocene (Stainforth, 1953).

Occurrence in Peru: Rare specimens have been observed in the Chira shale.

Globigerina topilensis Cushman
Plate 2, figures 16-17

Globigerina topilensis CUSHMAN, 1925, Cushman Lab. Foram. Res., Contr., vol. 1, p. 7, pl. 1, fig. 9.

The types of this species are from the Upper Eocene of Mexico. The hispid surface of the test is typical of

many of the Caribbean Eocene globigerinids. This feature, and the flat dorsal and convex ventral sides of the test, are also characteristic of the Upper Eocene species *Globorotalia crassata*. *Globigerina topilensis*, however, has a decidedly more lobulate periphery because of the greater separation of the individual chambers.

Occurrence in Peru: A common and excellent index foraminiferan for the Chira formation of northern Peru.

Gümbelina venezuelana Nuttall
Plate 2, figure 21

Gümbelina venezuelana Nuttall, 1935, Jour. Pal., vol. 9, p. 126, pl. 15, figs. 2-4.

The holotype of this small, thin-walled species is from the Upper Eocene of Venezuela. It has come to the writer's attention that Hofker, currently working on the Tertiary foraminifera of Ecuador, considers this species to be more closely related to the virgulinid foraminifera.

Occurrence in Peru: Another good Upper Eocene (Chira) marker of northern Peru.

Globigerina venezuelana Hedberg
Plate 2, figures 18-20

Globigerina venezuelana Hedberg, 1937, Jour. Pal., vol. 11, p. 681, pl. 92, fig. 7.

Globigerina venezuelana is somewhat similar to *Globigerina altispira* but has a more appressed, less quadrate coil, and hence a smaller, less gaping umbilicus. The species has been recorded from the Lower Oligocene to Middle Miocene of the Caribbean region.

Occurrence in Peru: Small, globose specimens are rare near the top of the Cone Hill formation. The species is common in the Oligocene of both the Zorritos and Sechura areas. There seems to be a tendency for the species to become larger and more robust in the Peruvian Oligocene sediments. The forms observed in the Lower Miocene Montera and succeeding beds are, like those of the late Eocene, small and few in number.

Globigerina dissimilis Cushman and Bermudez
Plate 2, figure 27

Globigerina dissimilis Cushman and Bermudez, 1937, Cushman Lab. Foram. Res., Contr., vol. 13, p. 25, pl. 3, figs. 4-6.

This species is characterized by a supplementary chamber which covers the umbilicus.

Occurrence in Peru: At the present time, *Globigerina dissimilis* has been observed only in the Heath shale of the Zorritos area.

Globorotalia fohsi Cushman and Ellisor
Plate 2, figures 24-26

Globorotalia fohsi Cushman and Ellisor, 1939, Cushman Lab. Foram. Res., Contr., vol. 15, p. 12, pl. 2, fig. 6.

This species differs from *Globorotalia barissanensis* in having more radially elongate chambers and a more acute periphery in the later portion of the test.

Globorotalia fohsi is an excellent Upper Oligocene marker in the Caribbean area, for example, in Cuba, Trinidad, and Venezuela, although the type is from a supposedly Miocene core from a Gulf Coast well. This could be a result of northward migration of the species through time, or, in the light of our present knowledge of Caribbean stratigraphy, the type locality of *Globorotalia fohsi* may well be Upper Oligocene in age.

Occurrence in Peru: A rare species in the undifferentiated Oligocene sediments of the Sechura Desert.

Globorotalia barissanensis LeRoy
Plate 3, figures 4-6

Globorotalia barissanensis LeRoy, 1939, Natuurk. Tijdschr. *Nederl.-Indië*, vol. 99, no. 6, p. 265, pl. figs. 8-10.

This small, distinctive species has been recorded from the Upper Oligocene of Trinidad, Colombia, and Cuba, and from the late Middle and Upper Oligocene of Ecuador (Stainforth, 1948). It has also been observed (Stainforth, personal communication) in the Upper Oligocene of the Jusepín area of Venezuela.

Occurrence in Peru: A common and useful guide fossil for the undifferentiated Oligocene sediments of the Sechura Desert. Recently, rare specimens have been seen in the Peruvian Lower Miocene Montera formation, but the appearance of *Globorotalia barissanensis* in quantity is still strongly suggestive of an Oligocene age.

Globigerina altispira Cushman and Jarvis
Plate 3, figures 1-3

Globigerina altispira Cushman and Jarvis, 1936, Cushman Lab. Foram. Res., Contr., vol. 12, p. 5, pl. 1, figs. 13-14.

A high-spired species, whose quadrate coil and wide, open umbilicus distinguish it from *Globigerina venezuelana*.

It is reported from the Miocene of Jamaica, Haiti, and the Middle East, and from the Upper Oligocene and Miocene of the Dominican Republic (Hamilton, 1953).

Occurrence in Peru: This species is fairly common in Peruvian sediments, ranging from Oligocene through Lower and possibly Middle Miocene formations.

Globigerina aff. **bulloides** d'Orbigny
Plate 3, figures 9-11

Globigerina aff. *bulloides* d'Orbigny. – STAINFORTH, 1948, Jour. Pal., vol. 22, p. 118, pl. 25, figs. 16-18.

This species seems to be identical with *Globigerina* aff. *bulloides*, form B, of Ecuador (Stainforth, 1948), where it ranges from the Middle Oligocene through the Miocene.

Occurrence in Peru: Common in the Heath formation of Zorritos and the undifferentiated Oligocene of the Sechura; rare in the Lower Miocene Montera formation and overlying beds.

Globigerina sp.
Plate 3, figures 15-16

This is a species which deserves mention although it is as yet unnamed. It is a small form, dorsally similar to the larger *Globigerina concinna*, but ventrally with more appressed chambers and a smaller umbilicus. Stainforth (personal communication) noted this species in the Upper Oligocene of Venezuela.

Occurrence in Peru: Rare throughout Oligocene to Middle Miocene sediments of northern Peru.

Globigerinella aequilateralis (Brady)
Plate 3, figs. 7-8

Globigerina aequilateralis BRADY, 1879, Quart. Jour. Micr. Sci., vol. 19, p. 285.

The characteristic nautiloid coil of this species serves as its most distinguishing feature. It has been reported from the late Oligocene and Miocene of the Caribbean province (Stainforth, 1948).

Occurrence in Peru: A fairly common species in the undifferentiated Oligocene of the Sechura Desert and the Heath formation of Zorritos; sparse to common in the Lower to Middle Miocene deposits of the Sechura region.

Globigerinoides conglobatus (Brady)
Plate 3, figure 17

Globigerina conglobata BRADY, 1879, Quart. Jour. Micr. Sci., vol. 19, p. 286.

Globigerinoides conglobata (Brady). – CUSHMAN AND STAINFORTH, 1945, Cushman Lab. Foram. Res., Spec. Publ. no. 14, p. 68, pl. 13, fig. 6.

This species differs from *Globigerinoides triloba* in its large final chamber and overall globular shape, but differentiation between immature forms of the two species is difficult. *Globigerinoides conglobatus* is known from the late Middle and Upper Oligocene of Trinidad and Ecuador, and from the Upper Oligocene of Colombia (Stainforth, 1948). It is also a good Upper Oligocene index form in eastern Venezuela (Stainforth, personal communication).

Occurrence in Peru: Although more common in Oligocene sediments of northern Peru, *Globigerinoides conglobatus* also ranges into the Lower Miocene Montera formation and succeeding beds of the Sechura Desert.

Globigerinoides sacculifer (Brady)
Plate 3, figure 20

Globigerina sacculifera BRADY, 1877, Geol. Mag., dec. 2, vol. 4, p. 535; 1884, Rept. Voy. Challenger, Zool., vol. 9, p. 604, pl. 80, figs. 11-17; pl. 82, fig. 4.

The bean-shaped rather than globular form of the final chamber is the most diagnostic feature of this species, which ranges from the Upper Oligocene through the Miocene of the Caribbean area.

Occurrence in Peru: Fairly common in the Oligocene and Lower to Middle Miocene of the Sechura region and in the Heath formation of the Zorritos area.

Globigerinoides triloba (Reuss)
Plate 3, figure 19

Globigerina triloba REUSS, 1850, Denkschr. K. Akad. Wiss. Wien, vol. 1, p. 274, pl. 47, fig. 11.

Globigerinoides triloba (Reuss). – CUSHMAN, 1946, Cushman Lab. Foram. Res., Contr., vol. 22, p. 20, pl. 4, figs. 16-18.

This is a simple, three-chambered, somewhat variable species which appears to range from the younger Oligocene through the Miocene of the Caribbean province.

Occurrence in Peru: A common, long-ranging species which has been observed in late Middle Oligocene through Middle Miocene sediments.

Globigerinoides ruber (d'Orbigny)
Plate 3, figure 18

Globigerina rubra d'Orbigny, 1839, in de la Sagra, Hist. Phys., Pol., Nat. Cuba, Foram., pp. 82-83, pl. 4, figs. 12-14.
Globigerinoides rubra (d'Orbigny). – Stainforth, 1948, Jour. Pal., vol. 22, p. 122, pl. 26, figs. 11-12.

A large, lofty-spired, quadrate form with prominent supplementary apertures. This species has an Upper Oligocene to Miocene range in the Caribbean area (Stainforth, 1948).

Occurrence in Peru: Rare in the Heath formation and undifferentiated Sechura Oligocene; more common in the Lower to Middle Miocene of the Sechura Desert.

Globorotalia mayeri Cushman and Ellisor
Plate 3, figures 12-14

Globorotalia mayeri Cushman and Ellisor, 1939, Cushman Lab. Foram. Res., Contr., vol. 15, p. 11, pl. 2, fig. 4.

This is a small species with a thick test and a broadly rounded periphery. The type locality is the same as that of *Globorotalia fohsi* (see above). It has also been recorded from the Middle and Upper Oligocene of Cuba (Cushman and Bermudez, 1949), and from the Upper Oligocene—basal Miocene of Trinidad (Bronnimann, 1951).

Occurrence in Peru: Common in the Heath formation near Zorritos, and rare in the Oligocene to Middle Miocene of the Sechura Desert.

Globigerinoides sp. indet.
Plate 3, figures 24-25

Globigerinoides sp. indet., Stainforth, 1948, Jour. Pal., vol. 22, p. 123, pl. 26, figs. 13-15.

Stainforth described this small species from the Miocene of Ecuador. It is a fairly high-spired form with a large, circular aperture on the ventral side of the last chamber.

Occurrence in Peru: Although scarce, this species appears to be a useful index fossil for the Lower to Middle Miocene of northern Peru.

Globorotalia menardii (d'Orbigny)
Plate 3, figures 21-23

Rotalia menardii d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, p. 273, no. 26, Modèle no. 10.
Globorotalia menardii (d'Orbigny). – Stainforth, 1948, Jour. Pal., vol. 22, p. 124, pl. 26, figs. 36-37.

This is a biconvex rotaloid species, with a heavy keel of opaque shell material as its most distinctive feature. It is an excellent Miocene marker for the Caribbean province (Stainforth, 1948).

Occurrence in Peru: Very rare in the shale beds overlying the Montera formation of the Sechura region.

Orbulina suturalis Bronnimann
Plate 3, figure 26

Orbulina suturalis Bronnimann, 1951, Cushman Found. Foram. Res., Contr., vol. 2, p. 135, tf. 2, figs. 1-5.

This species has a highly globular end-chamber, not quite enveloping the early *Globigerina*-chambers, which project slightly above the surface of the test.

Orbulina suturalis is recorded from the Miocene of Panama, Venezuela and the eastern Coastal Plain of the United States, and from the Upper Oligocene and Miocene of Trinidad, Ecuador, and Colombia (Stainforth, 1948).

Occurrence in Peru: At this writing, *Orbulina suturalis* appears to be limited in Peru to the Miocene. However, in view of the initial appearance of the *Orbulina* group in Caribbean sediments of well-established Oligocene age, the writer agrees with Bronnimann (1951) in questioning the validity of the *Orbulina* worldwide datum-line theory as proposed by LeRoy (1948) and Tromp (1949). It will be of considerable interest to see if future work will extend the range of *Orbulina* to the Oligocene in Peru, or if the genus will remain a good Miocene marker.

Orbulina bilobata (d'Orbigny)
Plate 3, figure 27

Globigerina bilobata d'Orbigny, 1846, Foram. Foss. Vienne, p. 164, pl. 9, figs. 11-14.
Orbulina bilobata (d'Orbigny). – Bermudez, 1949, Cushman Lab. Foram. Res., Spec. Publ. no. 25, p. 282, pl. 22, fig. 4.

This is a bilobate species consisting of an *Orbulina suturalis* stage and an additional chamber of variable size.

Bronnimann (1951) recognized a biostratigraphic series of assemblages in Trinidad beginning with *Orbulina suturalis* in the Upper Oligocene and developing through an *Orbulina suturalis—Orbulina bilobata* assemblage to the *Orbulina universa—Orbulina bilobata—Orbulina suturalis* assemblage of the Lower Miocene. Stainforth (personal communication) observed *Orbulina universa* and *Orbulina bilobata* in the uppermost Oligocene of Venezuela, above the *Orbulina suturalis* zone.

Occurrence in Peru: Wherever observed, *Orbulina bilobata* has always been part of an assemblage containing *Orbulina suturalis*. Rare specimens which may questionably be referred to *Orbulina universa* (pl. 3, fig. 30) were recorded from several wells at shallow depths. This may represent an upper *Orbulina* zone, although more specimens, and better preserved ones, are necessary for definite recognition.

Sphaeroidinella dehiscens (Parker and Jones)
Plate 3, figures 28-29

Sphaeroidina dehiscens PARKER AND JONES, 1865, Philos. Trans. Roy. Soc. London, vol. 155, p. 369, pl. 19, fig. 5.
Sphaeroidinella dehiscens (Parker and Jones). – STAINFORTH, 1948, Jour. Pal., vol. 22, p. 124, pl. 26, fig. 20.

This is a very distinctive species, with its thick, hyaline, coarsely perforate wall structure. It is considered a Miocene guide fossil for tropical America (Stainforth, 1948).

Occurrence in Peru: Only one specimen has been noted from the post-Montera Miocene of Peru, but it is identified with confidence.

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PLATE 1

1–2 *Globotruncana lapparenti lapparenti* Brotzen
1, dorsal view. 2, peripheral view. × 60.

3–5 *Globotruncana lapparenti bulloides* Vogler
3, dorsal view. 4, peripheral view. 5, ventral view. × 60.

6–7 *Globotruncana lapparenti tricarinata* (Quereau)
6, dorsal view. 7, peripheral view. × 60.

8 *Gümbelina globulosa* (Ehrenberg)
Side view. × 60.

9 *Rugoglobigerina rugosa* (Plummer)
Ventral view. × 60.

10 *Globigerina cretacea* d'Orbigny
Dorsal view. × 60.

11–13 *Globigerina pseudotriloba* White
11, dorsal view. 12, ventral view. 13, peripheral view. × 85.

14 *Gümbelina* cf. *trinitatensis* Cushman and Renz
Side view. × 85.

15–17 *Globigerina eocaenica* Terquem
15, dorsal view. 16, ventral view. 17, peripheral view. × 85.

18–19 *Globigerina triloculinoides* Plummer, Danian—Paleocene type
18, ventral view. 19, dorsal view. × 85.

20–21 *Globigerina triloculinoides* Plummer(?), Upper Eocene type
20, ventral view. 21, dorsal view. × 60.

22–23 *Globigerina trilocularis* d'Orbigny
22, peripheral view. 23, ventral view. × 85.

24–25 *Globorotalia wilcoxensis* Cushman and Ponton
24, ventral view. 25, dorsal view. × 85.

26–28 *Globorotalia crassata aequa* Cushman and Renz
26, ventral view. 27, dorsal view. 28, peripheral view. × 85.

29–30 *Globorotalia whitei* Weiss
29, dorsal view. 30, ventral view. × 85.

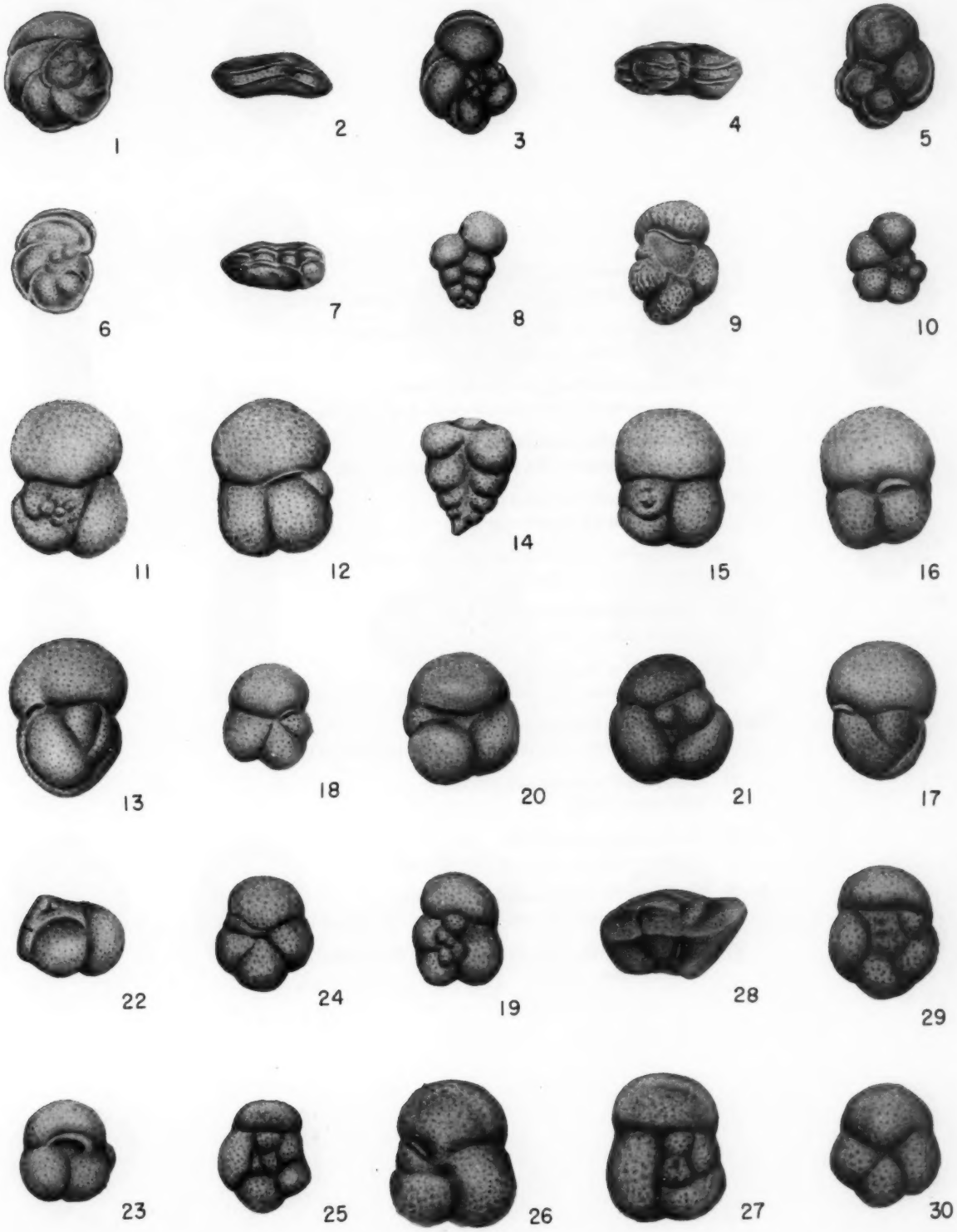
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PLATE 2

1–3 *Globigerina stonei* Weiss
1, dorsal view. 2, ventral view. 3, peripheral view. × 85.

4–5 *Globorotalia* cf. *membranacea* (Ehrenberg)
4, dorsal view. 5, ventral view. × 85.

6–8 *Globigerina wilsoni bolivariana* Petters
6, dorsal view. 7, peripheral view. 8, ventral view. × 60.

9–10 *Hastigerinella colombiana* Petters
9, single chamber. 10, whole specimen. × 60.

11–13 *Hastigerinella eocanica* Nuttall
Variable single chambers. × 60.

14 *Hantkenina primitiva* Cushman and Jarvis
Ventral view. × 60.

15 *Globigerina mexicana* Cushman
Dorsal view. × 60.

16–17 *Globigerina topilensis* Cushman
16, dorsal view. 17, ventral view. × 60.

18–20 *Globigerina venezuelana* Hedberg
18, dorsal view. 19, ventral view. 20, peripheral view. × 60.

21 *Gümbelina venezuelana* Nuttall
Side view. × 85.

22–23 *Globigerina wilsoni* Cole
22, ventral view. 23, dorsal view. × 60.

24–26 *Globorotalia fohsi* Cushman and Ellisor
24, ventral view. 25, peripheral view. 26, dorsal view. × 60.

27 *Globigerina dissimilis* Cushman and Bermudez
Ventral view. × 60.

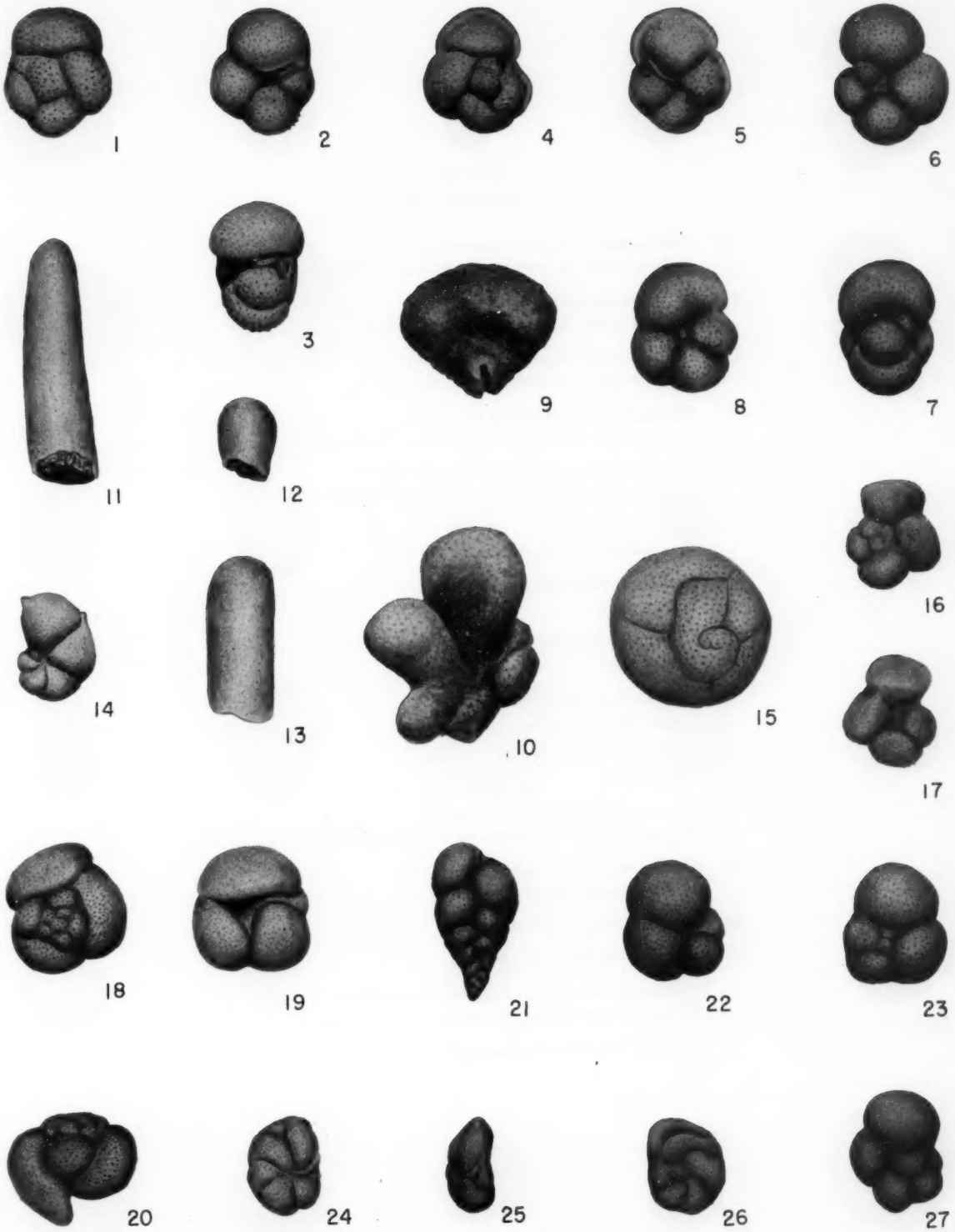
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PLATE 3
All figures × 60.

1–3 *Globigerina altispira* Cushman and Jarvis
1, dorsal view. 2, peripheral view. 3, ventral view.

4–6 *Globorotalia barissanensis* LeRoy
4, dorsal view. 5, peripheral view. 6, ventral view.

7–8 *Globigerinella aequilateralis* (Brady)
7, lateral view. 8, peripheral view.

9–11 *Globigerina* aff. *bulloides* d'Orbigny
9, peripheral view. 10, ventral view. 11, dorsal view.

12–14 *Globorotalia mayeri* Cushman and Ellisor
12, ventral view. 13, dorsal view. 14, peripheral view.

15–16 *Globigerina* sp.
15, ventral view. 16, dorsal view.

17 *Globigerinoides conglobatus* (Brady)
Lateral view.

18 *Globigerinoides ruber* (d'Orbigny)
Dorsal view.

19 *Globigerinoides triloba* (Reuss)
Dorsal view.

20 *Globigerinoides sacculifer* (Brady)
Dorsal view.

21–23 *Globorotalia menardii* (d'Orbigny)
21, ventral view. 22, dorsal view. 23, peripheral view.

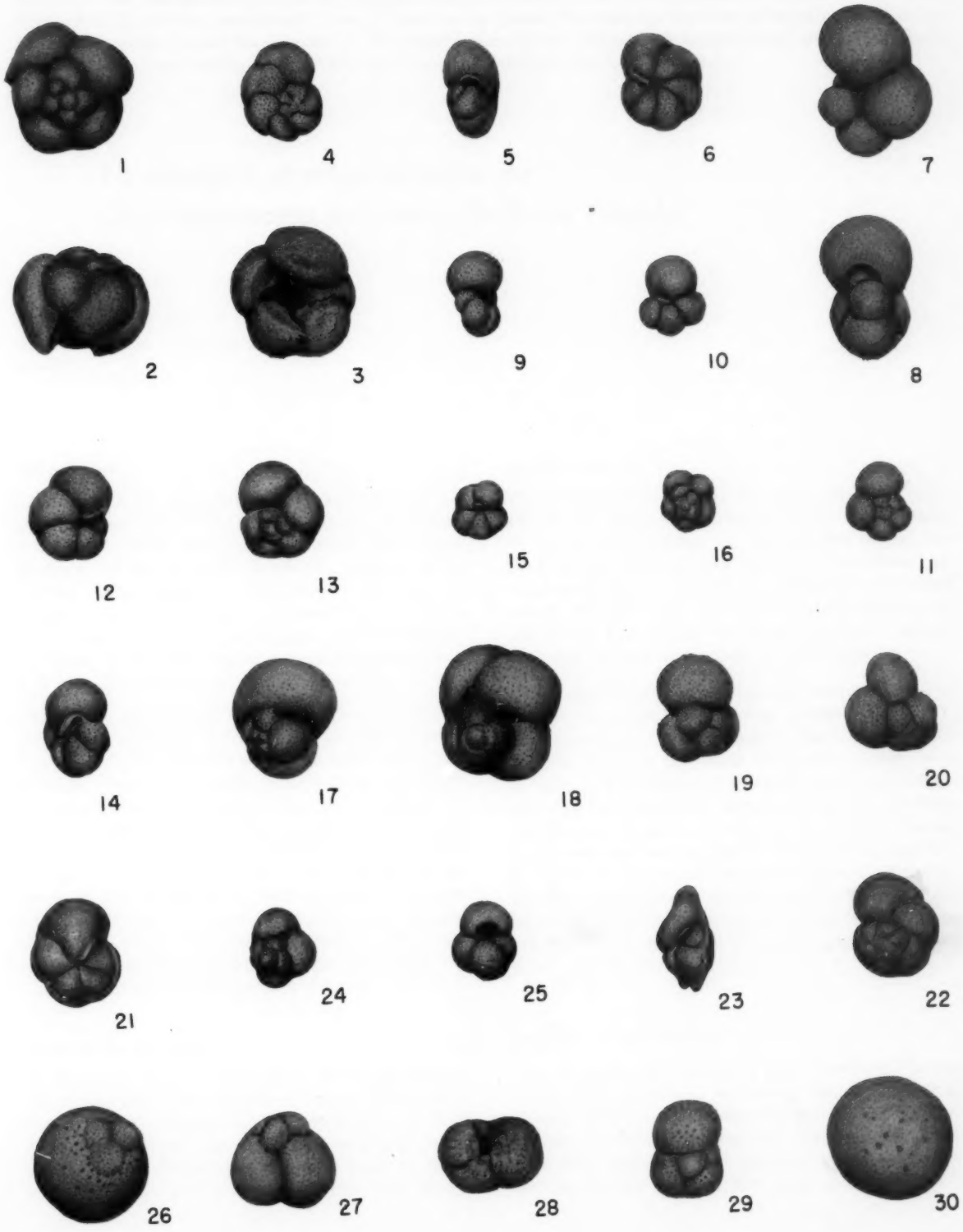
24–25 *Globigerinoides* sp. indet.
24, dorsal view. 25, ventral view.

26 *Orbulina suturalis* Bronnimann

27 *Orbulina bilobata* (d'Orbigny)

28–29 *Sphaeroidinella dehiscens* (Parker and Jones)
28, ventral view. 29, dorsal view.

30 *Orbulina universa* d'Orbigny(?)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ABSTRACT: *The stratigraphic position of* Globotruncana helvetica *Bolli in several sections in Tunisia is discussed. Although* G. helvetica *is considered to be an indicator of Lower Turonian age by most micropaleontologists, in Tunisia this species occurs much higher in the stratigraphic column. Megafossils found below, within and above the* G. helvetica *zone indicate a basal Senonian (Lower Coniacian) age for this zone.*

La position stratigraphique de Globotruncana helvetica Bolli en Tunisie

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INTRODUCTION

Cette espèce de foraminifère est considérée par les micropaléontologistes en général comme caractéristique du Turonien inférieur. En Tunisie, cette même espèce a été trouvée en de nombreux points et quelquefois accompagnée de macrofaunes. Ce sont ces dernières qui ont démontré nettement que la zone à *Globotruncana helvetica* ne se trouve pas à la base du Turonien, mais bien au-dessus, probablement même à la base du Coniacien.

J'ai utilisé pour ce travail les coupes et les échantillons mis à ma disposition par le service géologique de la S.E.R.E.P.T. Les macrofaunes de la région de Thala et de la zone à *G. helvetica* dans la coupe de l'Oued Massanerh ont été déterminées par Madame S. Arnould-Saget, paléontologiste au service géologique de la Direction des Travaux Publics à Tunis. La plupart de la taxonomie des mollusques a été vérifiée par Dr. L. R. Cox et par Dr. F. Spath du British Museum (Natural History) à Londres. Le Directeur Général de la S.E.R.E.P.T., Monsieur H. Mouly, a bien voulu donner l'autorisation de publier cette note. J'exprime ici mes plus vifs remerciements à tous.

DEFINITION DU TURONIEN

Le Turonien tunisien est le mieux développé dans la région comprise entre Kalaat es Senam, Djebel Semmama, Djebel Mrhila, Oued Massanerh et Le Kef-Nebeur. C'est dans cette région qu'il est le plus épais, le plus complet et c'est donc ici que nous avons choisi les coupes types pour étudier cet étage (voir fig. 1).

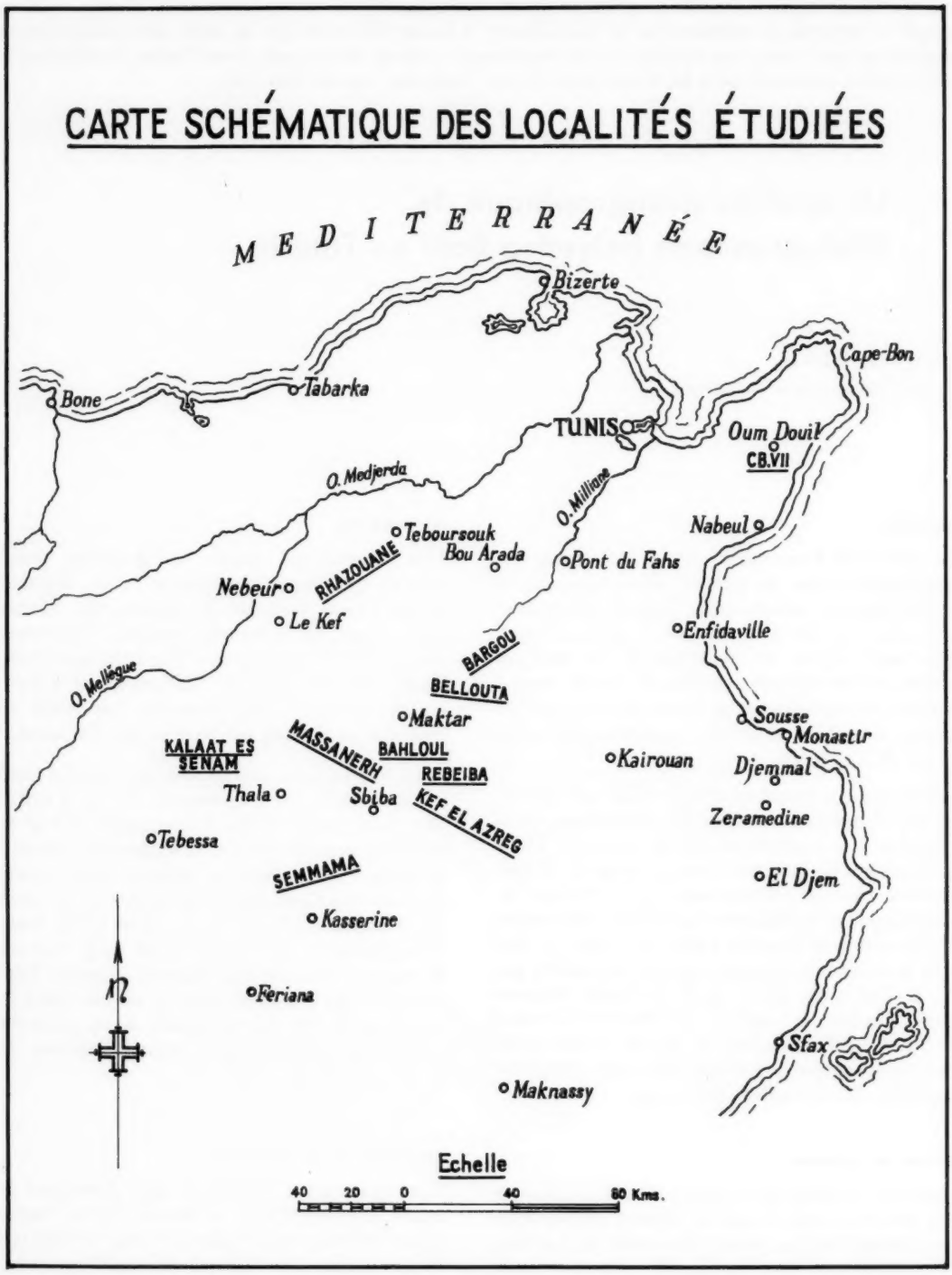
INTRODUCTION

This foraminiferal species has generally been considered by micropaleontologists to be characteristic of the Lower Turonian. In Tunisia, this species has been found at numerous localities, sometimes accompanied by macrofaunas. The latter have indicated clearly that the zone of *Globotruncana helvetica* is not at the base of the Turonian, but much higher, probably as high as the base of the Coniacian.

In this work I have used sections and samples furnished by the Geological Department of the S.E.R.E.P.T. The macrofaunas of the Thala region and of the *G. helvetica* zone in the Oued Massanerh section were indentified by Madame S. Arnould-Saget, paleontologist with the Geological Department of the Direction des Travaux Publics at Tunis. Most of the taxonomy of the mollusks was verified by Dr. L. R. Cox and Dr. F. Spath of the British Museum (Natural History), London. The Director General of the S.E.R.E.P.T., Monsieur H. Mouly, has kindly given permission to publish the present note. I express here my thanks to all concerned.

DEFINITION OF THE TURONIAN

The Turonian of Tunisia is best developed in the region between Kalaat es Senam, Djebel Semmama, Djebel Mrhila, Oued Massanerh and Le Kef-Nebeur. In this region it is thickest and most complete, and it is here, therefore, that we have chosen the type sections for the study of this stage (see text-fig. 1).



TEXT-FIGURE 1

Pervinquière (1903, pp. 94 à 109) donne très nettement les limites inférieures et supérieures de cet étage dans cette région. Je prends pour base les déterminations de ce grand géologue-paléontologiste. Ci-dessous un bref résumé de ces conclusions:

Sur les dernières assises du Cénomanien, caractérisées par *Neolobites vibrayeanus* et *Exogyra olisiponensis*, repose un banc de calcaire blanc, très dur, parfois un peu siliceux, parfois légèrement dolomitique, enfermant *Holectypus turonensis* Desor, *Thomasites rollandi* (Th. et P.), *Hemiaster* ou *Periaster*. Ce calcaire, dit "première masse calcaire du Turonien," constitue la base du Turonien. Il se transforme, surtout vers la région de Maktar, en marno-calcaire feuilleté, dit "calcaire en plaquettes."

Cette "première masse calcaire du Turonien" supporte des marnes bleues, un peu cendrées, devenant jaunes à l'air, beaucoup plus claires et un peu plus dures que les marnes cénomaniennes. Vers le milieu de ces marnes s'intercalent quelques lits calcaires qui deviennent de plus en plus nombreux vers le sommet. Dans la partie inférieure, les fossiles sont assez rares, tandis qu'ils abondent au milieu, particulièrement les ammonites, les lamellibranches du genre *Lima* et les gastéropodes du genre *Tylostoma*. Pervinquière (1903) y signale: *Phymosoma regulare* (Ag.), *P. majus* (Coq.), *P.* aff. *thevestense* (Coq.), *Orthopsis miliaris* Cott., *Hemiaster, Periaster verneuili* Desor, *Periaster* (différentes espèces), *Membranipora elliptica* Rss., *Inoceramus labiatus* Schloth., *Lima grenieri* Coq., *L. subsimplex* Th. et P., *L. delettrei* Coq., *"Cardium" productum* Sow., *"C." subproductum* Th. et P., *"Dosinia" cataleptica* Coq., *Cerithium sancti arromani* Th. et P., *Tylostoma cossoni* Th. et P., *Thomasites rollandi* (Th. et P.), *Holectypus turonensis* Des., *Pyrina, "Strombus," "Natica" aequiaxis* Coq., *Voluta, Fagisia superstes* (Kossm.), *Pseudaspidoceras salmuriensis* (Court.), *Collignoniceras douvillei* (Perv.), *Pteria* aff. *atra* (Coq.), *Plicatula, Biradiolites* cf. *cornu pastoris* d'Orb., *Aporrhais, Globiconcha, "Placenticeras?,"* et *Mammites nodosoides* Schloth. *Tylostoma cossoni* Th. et P. et *Thomasites rollandi* (Th. et P.) sont tout à fait caractéristiques du Turonien de la région centrale et pourraient être utilisés pour désigner ce niveau.

Sur ces marnes et lits calcaires repose un calcaire blanc, très dur, un peu siliceux, parfois dolomitique, renfermant par endroits des silex, surmonté d'une série de bancs calcaires. Nous appelons cet ensemble "deuxième masse calcaire du Turonien." Pervinquière y signale la présence de *Hippurites requieni* Math., des *Biradiolites* voisins de *B. lumbricalis* d'Orb., *Phy-*

Pervinquière (1903, pp. 94-109) defined very clearly the lower and upper limits of this stage in this region. I shall take the determinations of that eminent geologist and paleontologist as a base. A summary of his findings is given below:

The uppermost beds of the Cenomanian, which are characterized by *Neolobites vibrayeanus* and *Exogyra olisiponensis*, are overlain by a bed of white limestone, very hard, sometimes slightly siliceous, sometimes somewhat dolomitic, containing *Holectypus turonensis* Desor, *Thomasites rollandi* (Th. and P.), and *Hemiaster* or *Periaster*. This limestone, called the "first calcareous mass of the Turonian," constitutes the base of the Turonian. It grades, especially toward the Maktar region, into a thin-bedded marly limestone called the "platy limestone."

This "first calcareous mass of the Turonian" underlies blue marls, somewhat grayish, becoming yellow upon exposure to the air, much lighter in color and somewhat harder than the Cenomanian marls. Toward the middle of these marls a few calcareous beds are intercalated, becoming more and more frequent toward the top. In the lower part, fossils are rather rare, but they are abundant in the middle portion, particularly ammonites, lamellibranchs of the genus *Lima*, and gastropods of the genus *Tylostoma*. Pervinquière (1903) reports from these beds: *Phymosoma regulare* (Ag.), *P. majus* (Coq.), *P.* aff. *thevestense* (Coq.), *Orthopsis miliaris* Cott., *Hemiaster, Periaster verneuili* Desor, *Periaster* (various species), *Membranipora elliptica* Rss., *Inoceramus labiatus* Schloth., *Lima grenieri* Coq., *L. subsimplex* Th. and P., *L. delettrei* Coq., *"Cardium" productum* Sow., *"C." subproductum* Th. and P., *"Dosinia" cataleptica* Coq., *Cerithium sancti arromani* Th. and P., *Tylostoma cossoni* Th. and P., *Thomasites rollandi* (Th. and P.), *Holectypus turonensis* Des., *Pyrina, "Strombus," "Natica" aequiaxis* Coq., *Voluta, Fagisia superstes* (Kossm.), *Pseudaspidoceras salmuriensis* (Court.), *Collignoniceras douvillei* (Perv.), *Pteria* aff. *atra* (Coq.), *Plicatula, Biradiolites* cf. *cornu pastoris* d'Orb., *Aporrhais, Globiconcha, "Placenticeras?,"* and *Mammites nodosoides* Schloth. *Tylostoma cossoni* Th. and P., and *Thomasites rollandi* (Th. and P.) are highly diagnostic for the Turonian in the central region, and can be used as markers for this horizon.

These marls and calcareous beds are overlain by a white limestone, very hard, somewhat siliceous, sometimes dolomitic, containing flint nodules in places, which in turn is followed by a series of calcareous beds. We call this complex the "second calcareous mass of the Turonian." Here Pervinquière reports

mosoma regulare (Ag.), *Holectypus turonensis* Desor, *Pyrina, Echinobrissus daglensis* Th. et Gh., *Tylostoma cossoni* Th. et P., et *Lewisiceras peramplus* (Mant.).

Pervinquière subdivise le Turonien en deux parties:

1) Turonien inférieur, caractérisé par *Periaster verneuili, Inoceramus labiatus, Thomasites rollandi, Neoptychites cephalotus* et *Mammites nodosoides.*
2) Turonien supérieur, caractérisé par *Lewisiceras peramplus* et *Hippurites requieni. Hippurites requieni* est cité le plus souvent du Turonien supérieur, mais quelquefois aussi du Sénonien inférieur, ce qui prouve que nous sommes ici vers la limite des deux étages.

Les marnes et calcaires qui viennent au-dessus de la "deuxième masse calcaire" sont à rattacher au Sénonien, car on y trouve *Ostrea boucheroni* Coq. (= *Liostrea thevestensis* Coq. et *Hemiaster fourneli* Desh.).

La suite lithologique citée ci-dessus est généralement bien reconnaissable sur le terrain dans cette région. Nous avons indiqué les unités sur les logs ci-dessous dans la mesure du possible.

Au point de vue micropaléontologique, le Turonien tunisien est bien encadré également. *Rotalipora globotruncanoides* Sigal (= *Rotalipora apenninica* (Renz) var. *typica* Gandolfi) et *Thalmanninella brotzeni* Sigal s'éteignent juste avant la première masse calcaire du Turonien ou son équivalent, le calcaire en plaquettes, tandis que *Globotruncana helvetica* Bolli apparait toujours peu après la deuxième masse calcaire du Turonien. Dans les régions où les unités lithologiques sont peu reconnaissables ou même disparues, nous nous fions à ces fossiles pour déterminer le Turonien. Nous avons pu constater que les répartitions verticales de *Rotalipora turonica* et de *R. cushmani* ne sont pas constantes.

Si on s'éloigne de la région centrale vers l'Est, nous voyons que ce Turonien s'amincit progressivement, de telle façon qu'on risque finalement de trouver *G. helvetica* presque tout de suite au-dessus de *R. globotruncanoides* (Cénomanien). Nous verrons plus bas que c'est à peu près le cas dans le sondage d'Enfidaville (Ef. I) et dans celui du Cap Bon (C.B. VII). Le Turonien y est extrêmement réduit.

Dans le Turonien tunisien nous voyons apparaître les *Globotruncana* bicarénées: *G. imbricata* Mornod, *G. lapparenti* Brotzen avec ses variétés, *G. linnei* (d'Orb.) et surtout *G. globigerinoides* Brotzen. La dernière espèce résulte probablement d'une évolution des "grosses globigérines" qui abondent dans le Turonien.

Hippurites requieni Math., *Biradiolites* similar to *B. lumbricalis* d'Orb., *Phymosoma regulare* (Ag.), *Holectypus turonensis* Desor, *Pyrina, Echinobrissus daglensis* Th. and Gh., *Tylostoma cossoni* Th. and P., and *Lewisiceras peramplus* (Mant.).

Pervinquière subdivides the Turonian into two parts:

1) Lower Turonian, characterized by *Periaster verneuili, Inoceramus labiatus, Thomasites rollandi, Neoptychites cephalotus,* and *Mammites nodosoides.*
2) Upper Turonian, characterized by *Lewisiceras peramplus* and *Hippurites requieni. Hippurites requieni* is most frequently reported from the Upper Turonian, but it is sometimes reported also from the Lower Senonian, which indicates that we are now close to the boundary between the two stages.

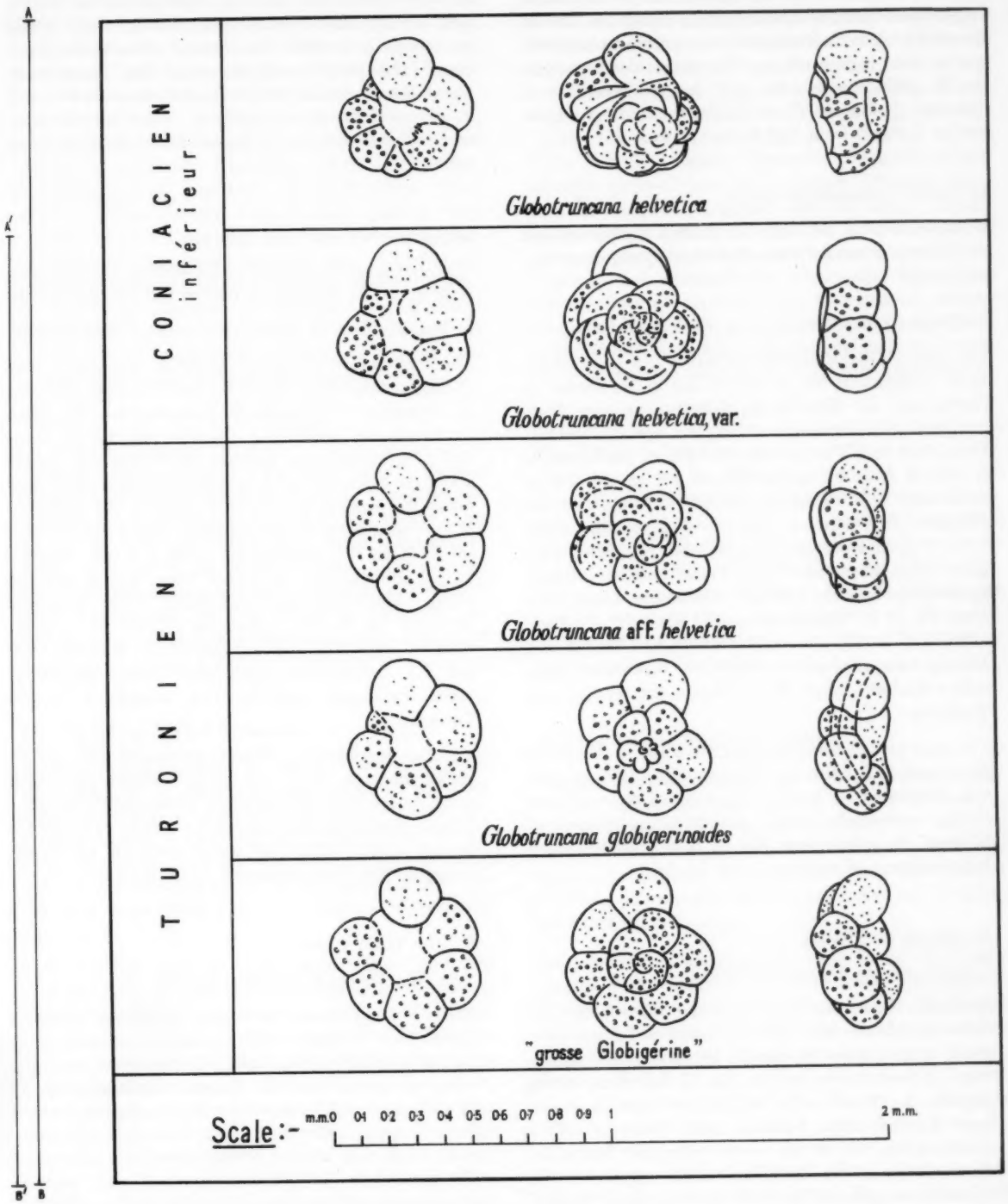
The marls and limestones which overlie the "second calcareous mass" are considered to be Senonian, since *Ostrea boucheroni* Coq. (= *Liostrea thevestensis* Coq.) and *Hemiaster fourneli* Desh. are found in them.

The lithologic sequence described above is usually easily recognizable in the field in this region. Insofar as possible, we have indicated the various units in the logs given below.

The Turonian of Tunisia is equally well marked from the micropaleontological point of view. *Rotalipora globotruncanoides* Sigal (= *Rotalipora apenninica* (Renz) var. *typica* Gandolfi), and *Thalmanninella brotzeni* Sigal disappear just below the "first calcareous mass of the Turonian" or its equivalent, the platy limestone, whereas *Globotruncana helvetica* Bolli always appears just above the "second calcareous mass of the Turonian." In regions where these lithologic units are indistinct or absent, we can rely on these fossils in defining the Turonian. We have found that the vertical distribution of *Rotalipora turonica* and of *R. cushmani* is not constant.

Away from the central region, toward the east, the Turonian thins progressively to such an extent that *G. helvetica* may be found immediately above *R. globotruncanoides* (Cenomanian). We will see below that this is almost exactly what happens in the Enfidaville well (Ef. I) and in the Cap Bon well (C.B. VII). Here the Turonian is extremely reduced.

In the Turonian of Tunisia we find bicarinate species of *Globotruncana: G. imbricata* Mornod, *G. lapparenti* Brotzen with its varieties, *G. linnei* (d'Orb.), and especially *G. globigerinoides* Brotzen. The latter species probably evolved from the "large globigerines" which



TEXT-FIGURE 2

Souvent on trouve déjà des spécimens qui annoncent l'apparition de *G. helvetica* juste au-dessous et dans la deuxième masse du Turonien. Le calcaire en plaquettes qui se situe juste au-dessus du niveau de disparition des *R. globotruncanoides* et *T. brotzeni*, contient de "grosses globigérines" et *Globotruncana globigerinoides* Brotzen (voir fig. 2).

DESCRIPTION DE QUELQUES COUPES

Nous préciserons ci-dessous la position stratigraphique de *Globotruncana helvetica* Bolli dans quelques coupes en Tunisie:

I. Coupe de Koudiat El Afna—Kalaat es Senam

La zone à *Globotruncana helvetica* qui a au moins 15 m. d'épaisseur ici, se trouve 350 m. au-dessus de l'extinction de *Rotalipora globotruncanoides* Sigal (= *Rotalipora apenninica* (Renz) var. *typica* Gandolfi). Un niveau fossilifère se trouvant 200 m. au-dessus de la zone à *R. globotruncanoides* et 150 m. au-dessous de la zone à *G. helvetica*, contient la faune suivante (d'après Pervinquière, 1903): *Phymosoma majus* (Coq.), *P. thevestense* (Coq.), *P.* aff. *regulare* (Ag.), *Holectypus turonensis* Des., *Pteria gravida* (Coq.), *Inoceramus labiatus* Schloth., *Cerithium sancti arromani* Th. et P., *Tylostoma cossoni* Th. et P., *"Voluta" villei* Th. et P., *Thomasites rollandi* (Th. et P.), *Neoptychites cephalotus* Court., et *Mammites nodosoides* Schloth. L'âge de ce niveau est typiquement Turonien.

Un autre niveau fossilifère se trouve 190 m. au-dessus de la zone à *G. helvetica*. Pervinquière (1903, p. 127) y a déterminé les formes suivantes: *Ostrea (Pycnodonte) vesicularis* Lamk., *Hemiaster, Modiolus,* et *"Natica"* cf. *subexcavata* Th. et P. Il considère cette faune comme sénonienne (voir fig. 3).

II. Région de Thala.

1) Coupe du Djebel et Tarfaoui.

Au-dessus du dernier banc calcaire du Turonien (calcaire blanchâtre avec de nombreux rudistes), nous avons trouvé dans les marnes jaune-brunâtre légèrement gypseuses vers la base, les *G. helvetica* accompagnées de *"Hoplitoides" ingens* von Koenen, *Hemiaster fourneli* Bay., *Fusinus fagesi* Perv., et débris d'ammonites; 30 m. au-dessus: *Durania bertholoni* Perv.; 20 m. au-dessus: *"Hoplitoides" ingens* von K., *Hemitissotia galeppi* Perv., *H. morreni* Coq., *"Voluta" conspicua* Coq., *"V." jullieni* Coq., *Lopha dichotoma* (Bay.), nautile, *Nucula*, et divers débris de gastéro-

are abundant in the Turonian. Specimens which forecast the appearance of *G. helvetica* are often found just below and within the "second mass of the Turonian." The platy limestone, which lies immediately above the horizon at which *R. globotruncanoides* and *T. brotzeni* disappear, contains "large globigerines" and *Globotruncana globigerinoides* Brotzen (see text-fig. 2).

DESCRIPTIONS OF INDIVIDUAL SECTIONS

The stratigraphic position of *Globotruncana helvetica* Bolli in certain sections in Tunisia is described below:

I. The Koudiat El Afna — Kalaat es Senam section.

The zone of *Globotruncana helvetica*, which is at least 15 meters thick here, lies 350 meters above the horizon of extinction of *Rotalipora globotruncanoides* Sigal (= *Rotalipora apenninica* (Renz) var. *typica* Gandolfi). A fossiliferous horizon which lies 200 meters above the zone of *R. globotruncanoides* and 150 meters below the zone of *G. helvetica* contains the following fauna (according to Pervinquière, 1903): *Phymosoma majus* (Coq.), *P. thevestense* (Coq.), *P.* aff. *regulare* (Ag.), *Holectypus turonensis* Des., *Pteria gravida* (Coq.), *Inoceramus labiatus* Schloth., *Cerithium sancti arromani* Th. and P., *Tylostoma cossoni* Th. and P., *"Voluta" villei* Th. and P., *Thomasites rollandi* (Th. and P.), *Neoptychites cephalotus* Court., and *Mammites nodosoides* Schloth. This horizon is typical Turonian.

Another fossiliferous horizon is found 190 meters above the zone of *G. helvetica*. Pervinquière (1903, p. 127) identified the following forms at this horizon: *Ostrea (Pycnodonte) vesicularis* Lamk., *Hemiaster, Modiolus,* and *"Natica"* cf. *subexcavata* Th. and P. He considers this fauna Senonian (see text-fig. 3).

II. The Thala region.

1) The Djebel et Tarfaoui section.

Above the uppermost calcareous bed of the Turonian (a whitish limestone with numerous rudistids), in brownish-yellow marls, slightly gypsiferous toward the base, we have found *G. helvetica* accompanied by *"Hoplitoides" ingens* von Koenen, *Hemiaster fourneli* Bay., *Fusinus fagesi* Perv., and fragments of ammonites; 30 meters higher: *Durania bertholoni* Perv.; 20 meters higher: *"Hoplitoides" ingens* von Koenen, *Hemitissotia galeppi* Perv., *H. morreni* Coq., *"Voluta" conspicua* Coq., *"V." jullieni* Coq., *Lopha dichotoma* (Bay.), a nautiloid, *Nucula*, and various fragments of

podes et d'ammonites; 26 m. au-dessus: *Durania flicki* Tou., *Ostrea (Pycnodonte)* cf. *costei* Coq., *Lapeirouseia,* et *Cyprina* cf. *barroisi* Coq.; 24 m. au-dessus: *Tissotia fourneli* Bay., *Hemiaster fourneli* Bay., et *Plicatula ferryi* Coq.; 36 m. au-dessus: *Hemiaster fourneli* Bay., et *Plicatula ferryi* Coq.; 14 m. au-dessus: *Hemiaster fourneli* Bay., et *Cyprina nicaisei* Coq.; 76 m. au-dessus: *Hemiaster,* débris d'ammonites, *Echinobrissus* cf. *angustior, Plicatula ferryi* Coq., nautile, *Cyprina barroisi* Coq., *"Voluta" jullieni* Coq., *Cyprina nicaisei* Coq., et *Liostrea;* 36 m. au-dessus: *Pholadomya, Hemiaster fourneli* Bay., *Cyprina,* et ammonites indéterminables; 112 m. au-dessus: *Cyprina nicaisei* Coq., *Plicatula* cf. *flattersi* Cor., et débris d'ammonites et de gastéropodes. Cette faune est essentiellement sénonienne et indique, surtout vers la partie inférieure, le Coniacien inférieur.

2) Coupe du Ksar Tlili.

Le contact Turonien-Sénonien se présente ici de la même façon qu'au Djebel et Tarfaoui. Dans les marnes jaune-brunâtre surmontant les derniers bancs de calcaire turonien, nous avons trouvé *G. helvetica* accompagnée de *"Cardium" biseriatum* Conr., *Durania,* et débris d'oursins et de lamellibranches; 110 m. plus haut: *Hemiaster fourneli* Bay., *Liostrea thevestensis* Coq., *L. thomasi* Per., et débris de plicatules, de gastéropodes et d'oursins réguliers. Cette faune est également considérée comme coniacienne.

III. Coupe du Djebel Semmama.

Ici nous avons rencontré la succession suivante: Juste au-dessous de la deuxième masse calcaire, qui constitue le sommet du Turonien, on a trouvé *Thomasites rollandi* (Th. et P.), *Periaster,* et divers lamellibranches et gastéropodes. Tout de suite au-dessus de ce même calcaire Pervinquière (1903, p. 98) signale la présence d'*Ostrea boucheroni* Coq. (= *Liostrea thevestensis* Coq.).

Globotruncana helvetica a été trouvée dans un faciès très peu profond directement au-dessus de ce dernier niveau fossilifère. Puis, environ 170 m. plus haut, Pervinquière (1903, p. 120) signale un ensemble assez fossilifère avec: *Phymosoma, Catopygus, Echinobrissus, Hemiaster* aff. *rollandi* Th. et Gh., *Janira, Lima (Plagiostoma) subsimplex* Th. et P., *Plicatula ferryi* Coq., *Ostrea (Lopha) dichotoma* Bay., *O. (Pycnodonte) vesicularis* Lamk., *O. (Pycnodonte) costei* Coq., *Protocardia pauli* Coq., *Nerinea,* et *Barroisiceras haberfellneri* (von Hau.). Environ 40 m. plus haut Pervinquière (1903, p. 121) signale *Arca maresi* Coq., *Ostrea (Pycnodonte) costei* Coq., *Trigonia,*

gastropods and ammonites; 26 meters higher: *Durania flicki* Tou., *Ostrea (Pycnodonte)* cf. *costei* Coq., *Lapeirouseia,* and *Cyprina* cf. *barroisi* Coq.; 24 meters higher: *Tissotia fourneli* Bay., *Hemiaster fourneli* Bay., and *Plicatula ferryi* Coq.; 36 meters higher: *Hemiaster fourneli* Bay., and *Plicatula ferryi* Coq.; 14 meters higher: *Hemiaster fourneli* Bay., and *Cyprina nicaisei* Coq.; 76 meters higher: *Hemiaster,* fragments of ammonites, *Echinobrissus* cf. *angustior, Plicatula ferryi* Coq., a nautiloid, *Cyprina barroisi* Coq., *"Voluta" jullieni* Coq., *Cyprina nicaisei* Coq., and *Liostrea;* 36 meters higher: *Pholadomya, Hemiaster fourneli* Bay., *Cyprina,* and unidentifiable ammonites; 112 meters higher: *Cyprina nicaisei* Coq., *Plicatula* cf. *flattersi* Cor., and fragments of ammonites and gastropods. This fauna is essentially Senonian and indicates, especially toward the lower part, the lower Coniacian.

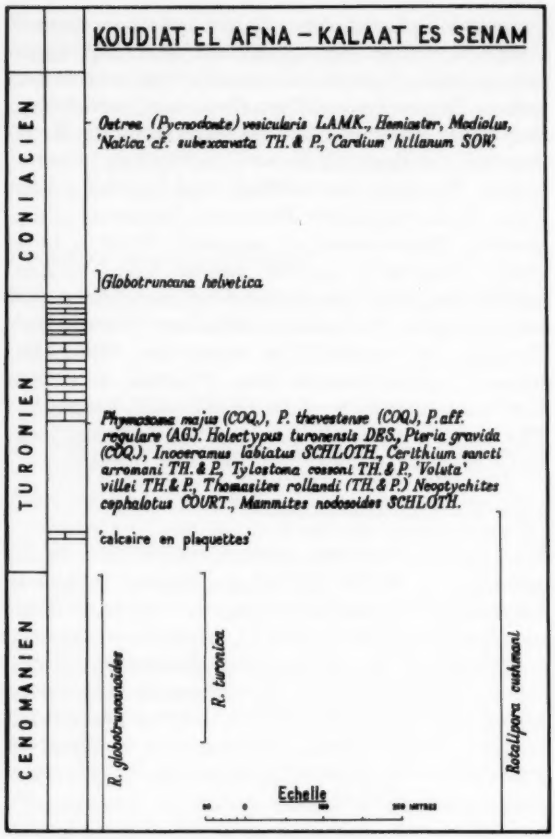
2) The Ksar Tlili section.

The Turonian-Senonian contact appears here in the same way as in the Djebel et Tarfaoui section. In brownish-yellow marls overlying the uppermost Turonian limestone beds, we find *G. helvetica* accompanied by *"Cardium" biseriatum* Conr., *Durania,* and fragments of echinoids and lamellibranchs; 110 meters higher: *Hemiaster fourneli* Bay., *Liostrea thevestensis* Coq., *L. thomasi* Perv., and fragments of Plicatulas, gastropods and symmetrical echinoids. This fauna is also considered Coniacian.

III. The Djebel Semmama section.

The following sequence is found here: Just below the "second calcareous mass," which constitutes the top of the Turonian, *Thomasites rollandi* (Th. and P.), *Periaster,* and various lamellibranchs and gastropods occur. Immediately above the limestone, Pervinquière (1903, p. 98) reports *Ostrea boucheroni* Coq. (= *Liostrea thevestensis* Coq.).

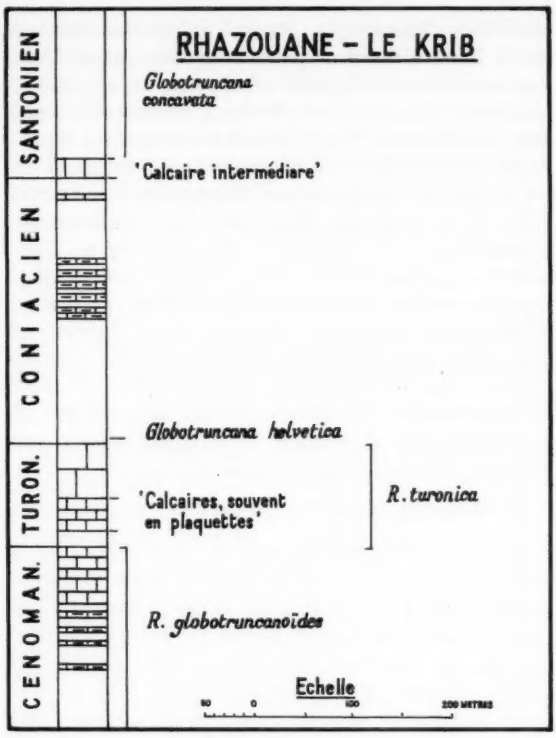
Globotruncana helvetica has been found in a very shallow-water facies immediately above the last-mentioned fossiliferous horizon. Then, about 170 meters higher, Pervinquière (1903, p. 120) indicates a rather fossiliferous unit with *Phymosoma, Catopygus, Echinobrissus, Hemiaster* aff. *rollandi* Th. and Gh., *Janira, Lima (Plagiostoma) subsimplex* Th. and P., *Plicatula ferryi* Coq., *Ostrea (Lopha) dichotoma* Bay., *O. (Pycnodonte) vesicularis* Lamk., *O. (Pycnodonte) costei* Coq., *Protocardia pauli* Coq., *Nerinea,* and *Barroisiceras haberfellneri* (von Hau.). About 40 meters higher, Pervinquière (1903, p. 121) reports *Arca maresi* Coq., *Ostrea (Pycnodonte) costei* Coq.,


KOUDIAT EL AFNA – KALAAT ES SENAM
CONIACIEN
TURONIEN
CENOMANIEN
Ostrea (Pycnodonte) vesicularis LAMK., Hemiaster, Modiolus, 'Natica' cf. subexcavata TH. & P., 'Cardium' hillanum SOW.
Globotruncana helvetica
Phymosoma majus (COQ.), P. thevestense (COQ.), P. aff. regulare (AG.). Holectypus turonensis DES., Pteria gravida (COQ.), Inoceramus labiatus SCHLOTH., Cerithium sancti arronni TH. & P., Tylostoma cossoni TH. & P., 'Voluta' villei TH. & P., Thomasites rollandi (TH. & P.) Neoptychites cephalotus COURT., Mammites nodosoides SCHLOTH.
'calcaire en plaquettes'
R. globotruncanoides
R. turonica
Rotalipora cushmani
Echelle
50 0 100 200 METRES

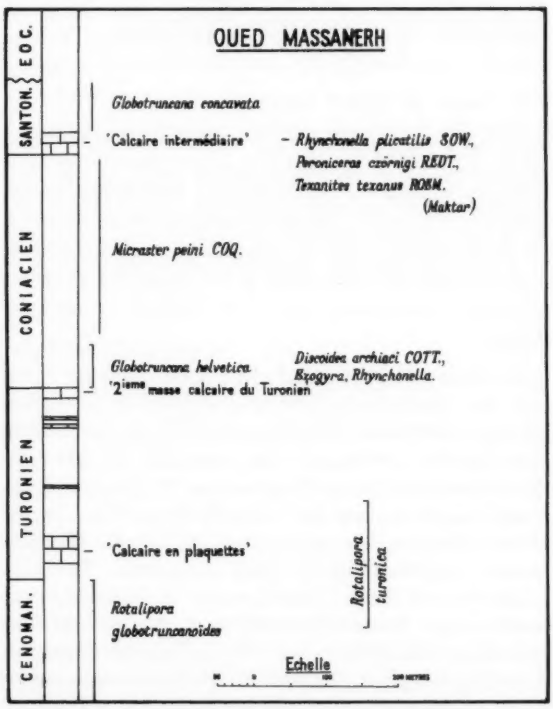
TEXT-FIGURE 3

DJEBEL SEMMAMA
SANTONIEN
CONIACIEN
CENOM.-TURONIEN
Tissotia aff. haplophylla, T. grossouvrei, Arca maresi, Ostrea (Pycnodonte) costei, Trigonia, Cyprina barroisi
Phymosoma, Catopygus, Echinobrissus, Hemiaster aff. rollandi, Janira, Lima (Plagiostoma) subsimplex, Plicatula ferryi, Ostrea (Lopha) dichotoma, O. (Pycnodonte) vesicularis, O. (Pycnodonte) costei, Protocardia pauli, Globiconcha incerta, Nerinea, Pteroceras cf. incerta, Barroisiceras haberfellneri
Globotruncana helvetica
Ostrea boucheroni = Liostrea thevestensis
'Deuxième masse calcaire du Turonien'
Thomasites rollandi
Echelle
50 0 100 200 METRES

TEXT-FIGURE 4



TEXT-FIGURE 5



TEXT-FIGURE 6

Cyprina barroisi Coq., *Tissotia* aff. *haplophylla* (Redt.), et *T. tissoti* Bay. var. *laevigata* Per. (= *Tissotia grossouvrei* Per.) (voir fig. 4).

C'est dans cette coupe que Pervinquière (1903, p. 121) a démontré nettement que les *Tissotia* gisent au-dessus du niveau à *Barroisiceras haberfellneri* (von Hau.), tout comme en France, et que, par suite, elles ne peuvent en aucune façon être rattachées au Turonien comme le voulait de Grossouvre.

IV. Coupe du Djebel Rhazouane — Le Krib.

Les *Globotruncana helvetica* se trouvent directement au-dessus du calcaire Turonien, c'est-à-dire 113 m. au-dessus du sommet de la zone à *Rotalipora globotruncanoides* et 415 m. au-dessous des bancs à *Inoceramus siccensis* Perv. Un calcaire d'une vingtaine de mètres d'épaisseur se trouve 260 m. au-dessus du niveau à *G. helvetica*. Ce calcaire constitue un excellent repère sur le terrain et il forme en même temps la base de la zone à *Globotruncana concavata* (Brotzen) (= *Globotruncana asymetrica* Sigal) (voir fig. 5). Nous considérons ce calcaire en question, que nous appelons "calcaire intermédiaire," comme la base du Santonien (voir plus bas, dans la coupe de l'Oued Massanerh).

V. Region de Maktar.

1) Coupe de l'Oued Massanerh.

Une zone à *Globotruncana helvetica* de 60 m. d'épaisseur environ surmonte la deuxième masse calcaire qui est considérée comme le sommet du Turonien. La base de cette zone à *G. helvetica* se trouve 265 m. au-dessus du sommet de la zone à *Rotalipora globotruncanoides*. Dans la zone à *G. helvetica* nous avons trouvé: *Discoidea archiaci* Cotteau, *Exogyra* sp., et *Rhynchonella* sp. La première masse calcaire du Turonien est constituée de "calcaire en plaquettes" qui atteint dans cette coupe 40 m. d'épaisseur et qui est située directement au-dessus de la zone à *R. globotruncanoides*. Le sommet de la zone à *G. helvetica* se trouve 290 m. au-dessous de la base de la zone à *G. concavata* (= *G. asymetrica*). Cette dernière surmonte le dit "calcaire intermédiaire" qui a 30 m. d'épaisseur à cet endroit. Dans le calcaire intermédiaire à Maktar, Pervinquière signale *Rhynchonella plicatilis* Sow., *Peroniceras czörnigi* Redt., et *Texanites texanus* (Roem.). Dans les marnes comprises entre la deuxième masse calcaire du Turonien et le calcaire intermédiaire, on trouve dans toute l'épaisseur *Micraster peini* Coq. (voir fig. 6).

Trigonia, Cyprina barroisi Coq., *Tissotia* aff. *haplophylla* (Redt.), and *T. tissoti* Bay. var. *laevigata* Per. (= *Tissotia grossouvrei* Per.) (see text-fig. 4).

It was in this section that Pervinquière (1903, p. 121) demonstrated unequivocally that *Tissotia* occurs above the horizon with *Barroisiceras haberfellneri* (von Hau.), just as it does in France, and that consequently *Tissotia* definitely cannot be referred to the Turonian, contrary to the opinion of de Grossouvre.

IV. The Djebel Rhazouane — Le Krib section.

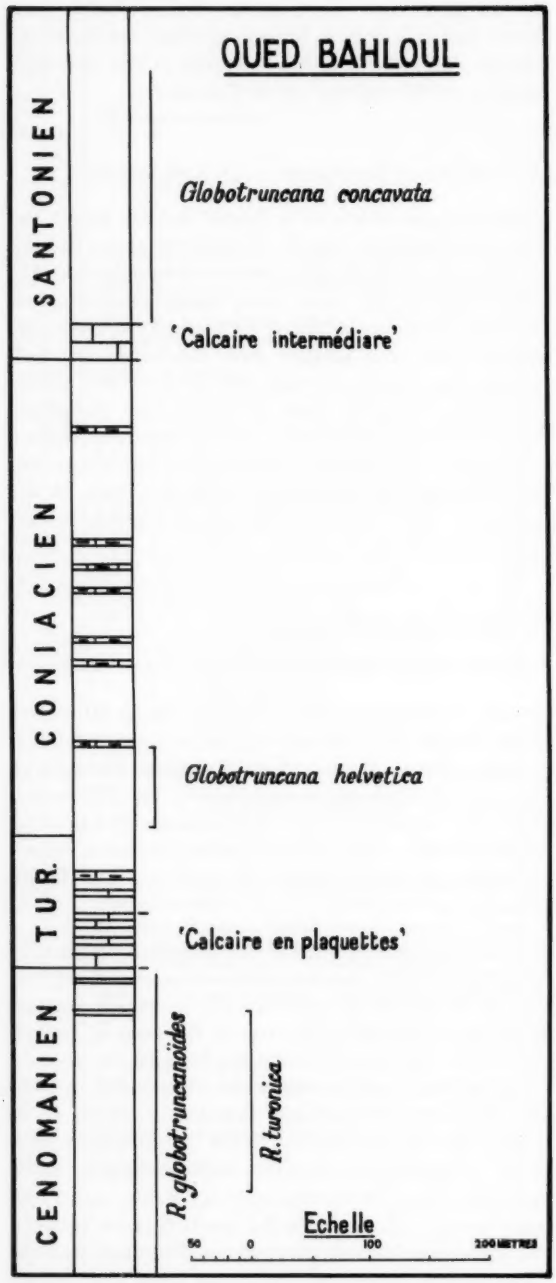
Globotruncana helvetica is found directly above the Turonian limestone, that is, 113 meters above the top of the zone of *Rotalipora globotruncanoides* and 415 meters below the beds with *Inoceramus siccensis* (Perv.). A limestone about 20 meters thick lies 260 meters above the horizon with *Globotruncana helvetica*. This limestone makes an excellent field guide, and it also forms the base of the zone of *Globotruncana concavata* (Brotzen) (= *Globotruncana asymetrica* Sigal). We consider this limestone, which we call the "intermediate limestone," to be the base of the Santonian (see below, in the Oued Massanerh section) (see text-fig. 5).

V. The Maktar region.

1) The Oued Massanerh section.

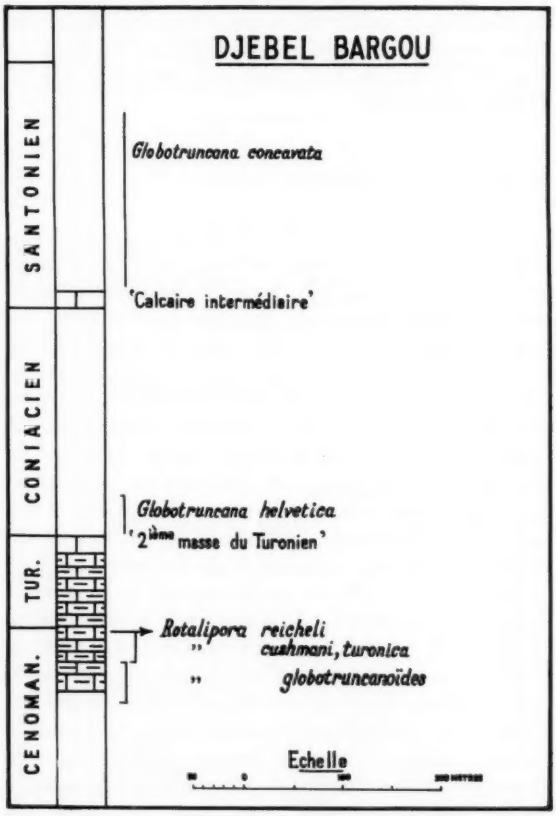
A zone of *Globotruncana helvetica*, about 60 meters thick, overlies the "second calcareous mass," which is considered to be the top of the Turonian. The base of this zone of *Globotruncana helvetica* lies 265 meters above the top of the zone of *Rotalipora globotruncanoides*. In the zone of *G. helvetica* we have found: *Discoidea archiaci* Cotteau, *Exogyra* sp., and *Rhynchonella* sp.

The "first calcareous mass of the Turonian" consists of "platy limestone," which in this section attains a thickness of 40 meters and lies directly above the zone of *R. globotruncanoides*. The top of the zone of *G. helvetica* lies 290 meters below the base of the zone of *G. concavata* (= *G. asymetrica*). The latter overlies the so-called "intermediate limestone," which is 30 meters thick at this locality. In the "intermediate limestone" at Maktar, Pervinquière indicates *Rhynchonella plicatilis* Sow., *Peroniceras czörnigi* Redt., and *Texanites texanus* (Roem.). In the marls that lie between the "second calcareous mass of the Turonian" and the "intermediate limestone," *Micraster peini* Coq. occurs throughout the sequence (see text-fig. 6).

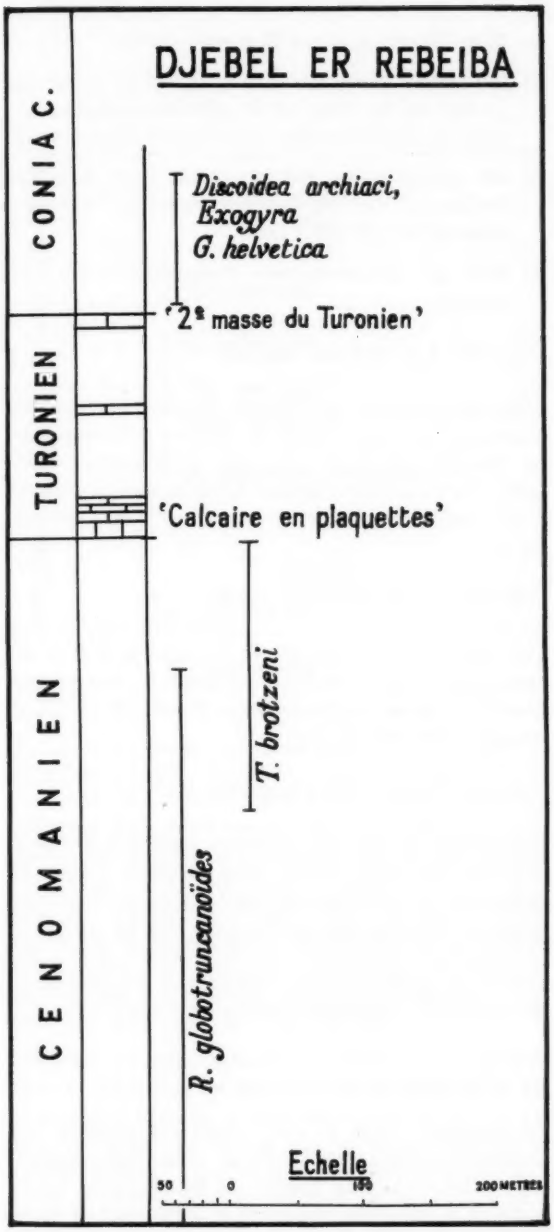


TEXT-FIGURE 7

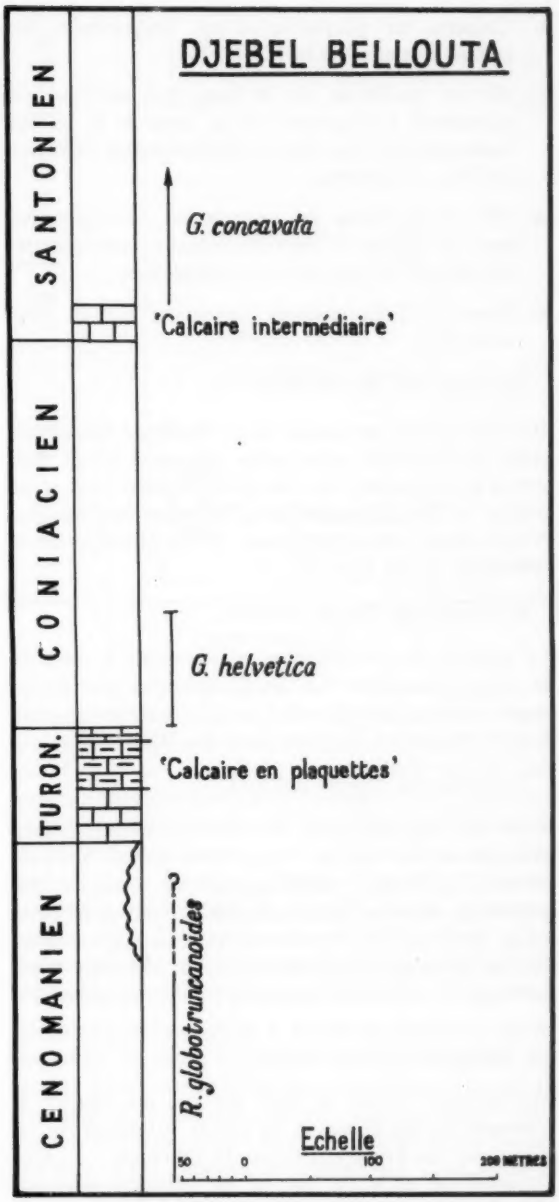
TEXT-FIGURE 8



TEXT-FIGURE 11



TEXT-FIGURE 9



TEXT-FIGURE 10

2) Coupe de l'Oued Bahloul.

Dans cette coupe nous trouvons la même suite lithologique et micropaléontologique (voir fig. 7). Malheureusement, nous ne disposons pas de données macropaléontologiques ici. Nous trouvons de bas en haut:

a) Zone à *R. globotruncanoides* et *R. turonica;*

b) Calcaire en plaquettes d'une cinquantaine de mètres d'épaisseur;

c) 120 m. au-dessus de la base des calcaires en plaquettes (= sommet da la zone à *R. globotruncanoides*), une zone à *Globotruncana helvetica* de 70 m. d'épaisseur;

d) 315 m. au-dessus du sommet de cette dernière zone se trouve la base du calcaire intermédiaire qui mesure ici une trentaine de mètres;

e) Zone à *Globotruncana concavata* (= *G. asymetrica*).

3) Coupe du Kef el Azreg.

Immédiatement au-dessus de la deuxième masse calcaire du Turonien, nous avons rencontré les *G. helvetica* accompagnées de *Discoidea archiaci* Cot. et de petites huitres *(Exogyra).* Le Turonien contient des *Neoptychites cephalotus* Court. et des *Hemiaster latigrunda* P. et Gh. (voir fig. 8).

4) Coupe du Djebel Rebeiba.

La position de *G. helvetica* est identique à celle de la coupe précédente. Ici, les *G. helvetica* sont également accompagnées de nombreuses *Discoidea archiaci* Cot. et de petites *Exogyra* (voir fig. 9).

5) Coupe du Djebel Bellouta.

Tout de suite au-dessus du calcaire turonien nous avons trouvé *G. helvetica* qui forme ici une zone de 90 m. d'épaisseur. Malheureusement, nous ne disposons de données macropaléontologiques pour cette coupe (voir fig. 10). Le calcaire intermédiaire se situe 212 m. au-dessus de l'extinction de *G. helvetica.* Il est suivi par la zone à *G. concavata (= G. asymetrica).*

VI. Coupe du Djebel Bargou.

Pervinquière (1903, p. 102) n'a pas pu séparer le Cénomanien du Turonien, ni par la paléontologie (il n'y a pas de fossiles), ni par la lithologie (ils font partie d'une série de 140 m. de calcaires marneux gris-clair ou gris-blanchâtre en bancs épais avec quelques rares intercalations marneuses). Il dit bien

2) The Oued Bahloul section.

In this section (see text-fig. 7) we find the same lithologic and micropaleontological sequence. Unfortunately, we have no macropaleontological data on this locality. We find, from bottom to top:

a) Zone of *R. globotruncanoides* and *R. turonica;*

b) Platy limestone about 50 meters thick;

c) 120 meters above the base of the platy limestones (= top of the zone of *R. globotruncanoides*), a zone of *Globotruncana helvetica* 70 meters thick;

d) 315 meters above the top of the latter zone lies the base of the "intermediate limestone," which is about 30 meters thick here;

e) Zone of *Globotruncana concavata* (= *G. asymetrica*).

3) The Kef El Azreg section.

Immediately above the "second calcareous mass of the Turonian," we have found *G. helvetica* accompanied by *Discoidea archiaci* Cot. and small oysters *(Exogyra).* The Turonian contains *Neoptychites cephalotus* Court. and *Hemiaster latigrunda* P. and Gh. (see text-fig. 8).

4) The Djebel Rebeiba section.

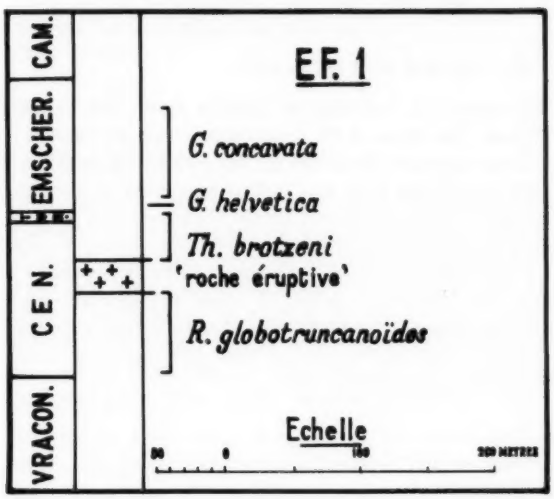
The position of *G. helvetica* is the same as it is in the preceding section. Here *G. helvetica* is also accompanied by numerous *Discoidea archiaci* Cot. and small *Exogyra* (see text-fig. 9).

5) The Djebel Bellouta section.

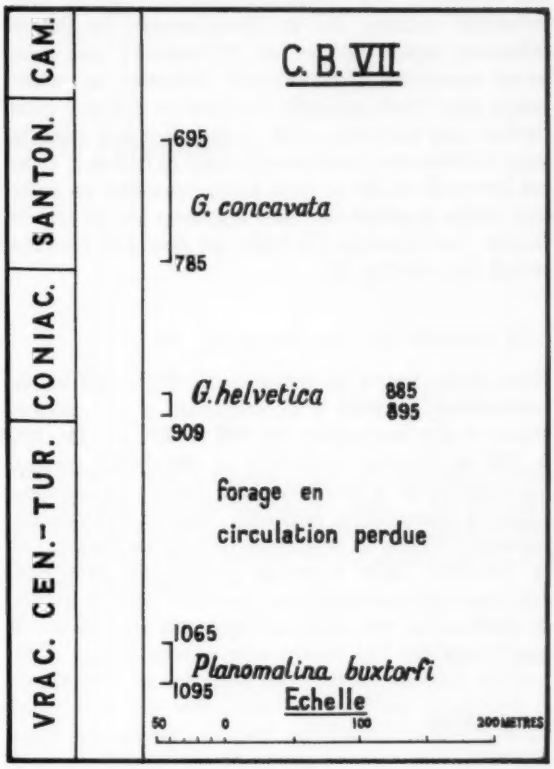
Immediately above the Turonian limestone, we have found *G. helvetica,* which here occupies a zone 90 meters thick. Unfortunately, we have no macropaleontological data for this section (see text-fig. 10). The "intermediate limestone" lies 212 meters above the horizon of extinction of *G. helvetica.* It is followed by the zone of *G. concavata* (= *G. asymetrica*).

VI. The Djebel Bargou section.

Pervinquière (1903, p. 102) could not separate the Cenomanian from the Turonian, either paleontologically (there were no fossils) or lithologically (they cosist of a 140-meter sequence of light gray or grayish white thick-bedded marly limestones with a few rare marl intercalations). He did predict that the



TEXT-FIGURE 12



TEXT-FIGURE 13

que la limite entre ces deux étages doit se trouver dans cette série de marno-calcaires. En effet, elle se trouve d'après l'étude des foraminifères à 60 m. au-dessus de la base de cet ensemble: extinction des espèces de *Rotalipora* et *Thalmanninella*, coincidant avec un niveau à *R. reicheli*, surmonté par les bicarénées; les *Gümbelina* avaient déjà débuté en même temps que les *R. turonica*, c'est-à-dire 20 m. au-dessous de la limite Turonien-Cénomanien. Le Turonien se termine par un calcaire beige, correspondant à la deuxième masse calcaire du Turonien.

Les *Globotruncana helvetica* se trouvent immédiatement au-dessus de ce dernier banc calcaire de 12 m. d'épaisseur; la zone a une épaisseur de 40 m. La base se trouve à 100 m. du niveau à *Rotalipora reicheli* (limite Turonien-Cénomanien) et le sommet à 184 m. de la base du calcaire intermédiaire. Ce dernier a une épaisseur de 16 m. dans cette coupe et il est surmonté par la zone à *Globotruncana concavata* (= *G. asymetrica*) (voir fig. 11).

boundary between these two stages would be found within this sequence of marly limestones. Actually, it was found, as a result of foraminiferal studies, 60 meters above the base of this complex; the horizon of extinction of the species of *Rotalipora* and *Thalmanninella* coincides with a zone of *R. reicheli*, which is succeeded by bicarinate forms; *Gümbelina* appears contemporaneously with *R. turonica*, that is, 20 meters below the Turonian-Cenomanian boundary. The Turonian ends with a beige limestone, corresponding to the "second calcareous mass of the Turonian."

Globotruncana helvetica is found immediately above the latter limestone bed, which is 12 meters thick; its zone is 40 meters thick. Its base lies 100 meters above the zone of *Rotalipora reicheli* (the Turonian-Cenomanian boundary), and its top lies 184 meters below the base of the "intermediate limestone." The latter is 16 meters thick in this section and is overlain by the zone of *Globotruncana concavata* (= *G. asymetrica*) (see text-fig. 11).

VII. Sondage d'Enfidaville (Ef. I).

Les épaisseurs des étages du Crétacé supérieur sont tellement réduites ici et l'avancement du forage tellement rapide (64 m. en 18 heures!) que nous avons rencontré *Globotruncana helvetica* en même temps que *Thalmanninella brotzeni* (à 448 m.) pour tomber une soixantaine de mètres plus bas dans la zone à *Rotalipora globotruncanoides* (à 510 m.). Dans cet intervalle de 60 m. nous avons rencontré en outre une roche éruptive sur une épaisseur de 27 m. de forage. Le Turonien, s'il existe, est donc extrêmement réduit ici (voir fig. 12).

VIII. Sondage du Cap Bon (C.B. VII).

Nous avons trouvé *G. helvetica* de 885 à 895 m. de profondeur. La zone à *G. concavata* (= *G. asymetrica*) a été rencontrée de 695 à 785 m. De 909 à 1065 m. le trou a été foré en circulation perdue. La microfaune à partir de 1065 m. est vraconienne (Zone à *Planomalina buxtorfi*). Tout le Cénomanien supérieur (Zone à *Rotalipora globotruncanoides)* et le Turonien (Zone à grosses globigérines et *Globotruncana globigerinoides)* se trouvent donc entre 900 et 1065 m. et ont ainsi une épaisseur de 165 m. en tout (voir fig. 13).

VII. The Enfidaville well (Ef. I).

The thicknesses of the Upper Cretaceous stages are so reduced here, and the progress of drilling was so rapid (64 meters in 18 hours!), that we found *Globotruncana helvetica* together with *Thalmanninella brotzeni* (at 448 meters), and then came suddenly upon the zone of *Rotalipora globotruncanoides* about 60 meters below (at 510 meters). Within this 60-meter interval we also encountered an eruptive rock with a drilled thickness of 27 meters. The Turonian, if it exists here, is therefore extremely reduced (see text-fig. 12).

VIII. Cap Bon well (C.B. VII).

We found *G. helvetica* at depths from 885 to 895 meters. The zone of *G. concavata* (= *G. asymetrica*) was encountered from 695 to 785 meters. From 909 to 1065 meters the hole was drilled in a zone of lost circulation. The microfauna below 1065 meters is Vraconian (zone of *Planomalina buxtorfi*). The entire Upper Cenomanian (zone of *Rotalipora globotruncanoides*) and the Turonian (zone of large globigerines and *Globotruncana globigerinoides*) lies therefore between 900 and 1065 meters and is thus 165 meters in total thickness (see text-fig. 13).

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ABSTRACT: *A resumé of the work that has been done on holothurian sclerites is presented, and their morphology is described. A new system of classification is proposed. The stratigraphic relationships and paleoecology of holothurian sclerites are also discussed.*

Micropaleontology of holothurian sclerites

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INTRODUCTION

Holothurians, commonly known as sea-cucumbers, are soft-bodied marine animals belonging to the phylum Echinoderma and the class Holothuroidea. They inhabit the oceans at all latitudes and all depths, but are almost completely restricted to water of normal salinity. As fossils, they may occur as impressions of the whole organism, or only the minute calcareous particles from their bodies may be preserved.

Numerous casts and impressions of problematical organisms have been referred to the Holothuroidea, from Cambrian, Ordovician, and younger rocks, and have been the basis for important conclusions about the origin and evolution of the class. Unfortunately, however, these identifications are almost entirely erroneous. Only two authentic fossil records of entire specimens are known, both from the Jurassic Solenhofen limestone of Germany. All conclusions about the early history of the Holothuroidea must therefore be revised in the light of knowledge of the isolated skeletal elements, the sclerites, that can be found in micropaleontological samples.

Sclerites (text-figs. 1 and 2) are microscopic, ranging from about 0.05 mm. to more than 1 mm. in greatest dimension. Although differing greatly in shape, they counterfeit many common household objects and, perhaps with some use of the imagination, are grouped as wheels, rods, plates, tables, baskets, spectacles, and so on. Functionally, sclerites serve to reinforce the holothurian body, in much the way that the framework of spicules supports the body of a sponge. In derivation, they are homologous with the joined plates of echinoids and pelmatozoan echinoderms, such as the crinoids and blastoids. They are, however, modified paedomorphotic structures. That is to say, they are comparable to the larval plates of the older echinoderm groups, rather than to the adult skeleton of the plated echinoderms.

Fossil holothurian sclerites were first discovered in 1843, and a species was named by Münster. Other forms were described or noted in the ensuing century, more than 100 references having been assembled in our bibliography (Frizzell and Exline, in press). With few exceptions, though, these records deal only very casually with the micropaleontology of sclerites. Critical and extensive work has been reported in a very few papers: in an excellent study of Carboniferous forms, by Etheridge (1881); in Schlumberger's detailed accounts of Eocene species (1888, 1890); in Croneis and McCormack's basic monograph of Carboniferous genera and species (1932); in the work of Bartenstein (1936) and Mortensen (1937) on Jurassic sclerites; and in a series of studies by Deflandre-Rigaud (1946, 1949, 1951, 1952). A single summary of stratigraphic occurrences has appeared (Sieverts-Doreck, 1943), an excellent compilation that is weakened by inclusion of many non-holothurian and non-sclerite records.

If fossil sclerites are to govern concepts of holothurian evolution, and if they are to be applied to the practical problems of correlation and paleoecology, a workable classification and system of nomenclature must be available. To date, however, no satisfactory overall classification has been published, although progress has recently been made in that direction. Our contribution (Frizzell and Exline, in press) is intended to fill this taxonomic hiatus with a comprehensive

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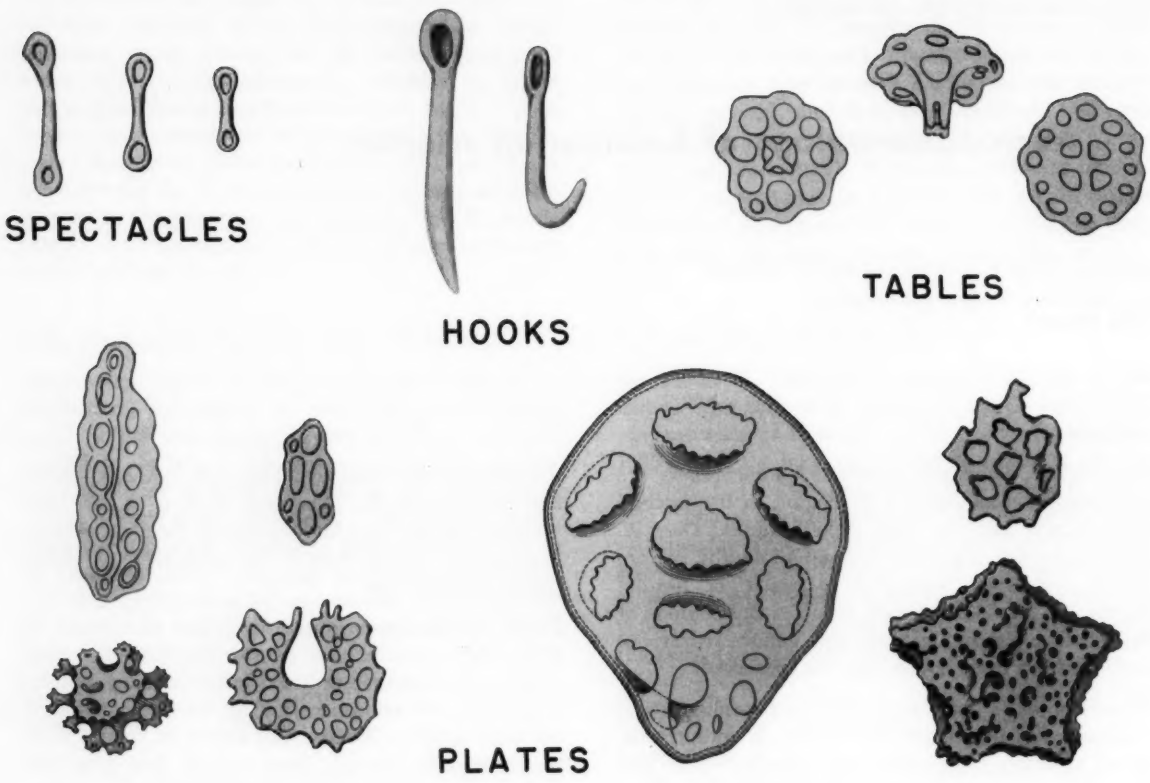


HOLOTHURIAN SCLERITES

TEXT-FIGURE 1

Holothurian sclerites in form of spectacles, hooks, tables and plates, from various sources and at different magnifications. The largest plate and the central table are inverted.

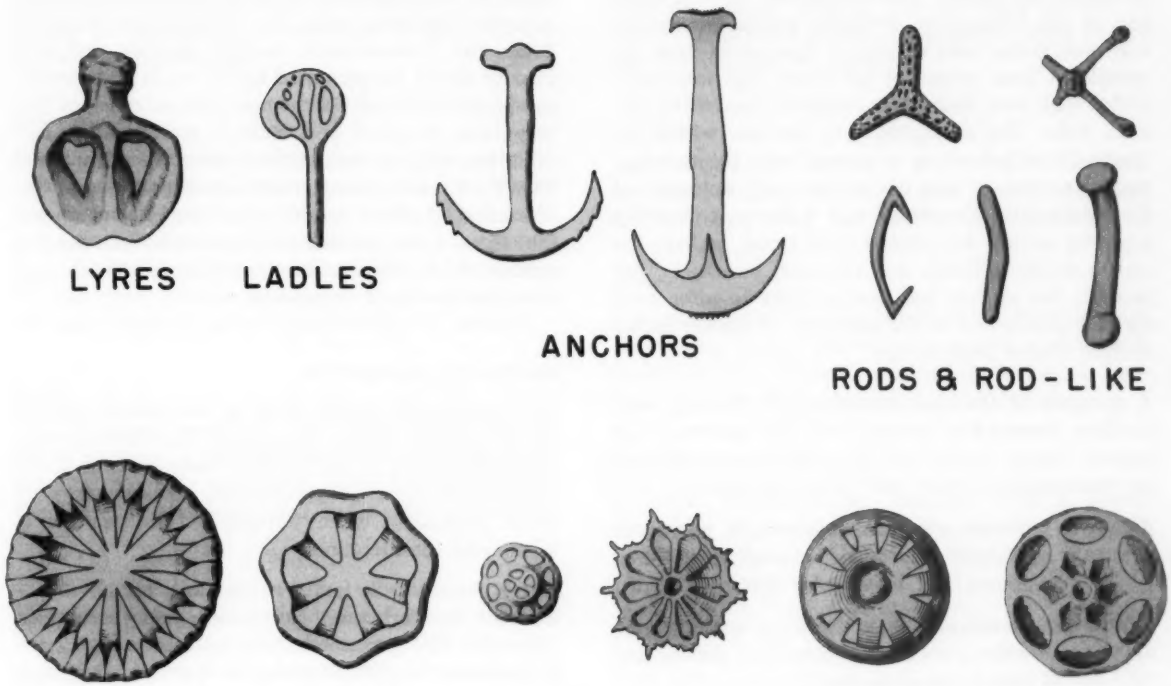
classificatory arrangement and nomenclatural system that will cover all known sclerites and will allow expansion as additional genera and species are discovered.

The new classification is based almost exclusively upon material that has already been published. We feel that known forms should be allocated before new collections are described. As a background for the systematic revision, we have examined in detail a number of Recent species; we have reexamined topotype collections of Pennsylvanian sclerites; and we have studied suites of completely undescribed forms from Cretaceous and Cenozoic formations.

CLASSIFICATION

The nomenclature of fragmental microfossils poses many problems, and authorities disagree markedly in suggested solutions. Obviously, any organism is likely to have dissimilar parts, and, conversely, unrelated organisms may possess structures that are similar or identical. Some structures are compatible with a natural classification, whereas others can be grouped only in an entirely artificial arrangement.

A number of diverse nomenclatural systems have been applied to fossil holothurian sclerites. Some authors have referred them to Recent genera, with or without



HOLOTHURIAN SCLERITES

TEXT-FIGURE 2

Holothurian sclerites in form of lyres, ladles, anchors, rods and wheels, from various sources and at different magnifications.

restrictive specific names for the fossils. Others have listed them without zoological names, although occasionally with such descriptive terms as "seven-spoked wheels" or "tetra-radiate bodies." Recent genera have been associated with unnamed forms, and sometimes with genera based entirely upon fossil species. One authority used zoological genera for presumably identifiable forms, contrasted with "pseudogenera" for species of uncertain position. The latest classification (Deflandre-Rigaud, 1953) follows Croneis's (1938) "ordo militaris," or military classification, with non-Linnean "manipuli" occupying the position and function of the Linnean genera of the zoological classification.

Our new classification is framed within the general requirements of the International Rules of Zoological Nomenclature: It is binominal; it accepts the Law of Priority; it involves the use of type genera and species; and it employs the descending hierarchy of family, genus, and species, although orders have not yet proved desirable. It attains objectivity through acceptance of the fictitious assumption that different kinds of sclerites belong to distinct species, thus avoiding the subjectivity and irresoluble controversies that would be caused by attempts to name sclerite assemblages. It parallels the presumed natural arrangement to a surprising extent, even though some families and genera are somewhat heterogeneous.

The new classification is based first on the objective criteria of sclerite pattern. Rods and rod-like forms constitute one family, wheels another, tables a third, and so on. Genera are definable groups of species, with intergrades rare or absent. Species, in turn, are postulated from groups of specimens that intergrade within their own limits, but constitute apparently discrete units. The arrangement of families, within the classification, follows in a general way the developmental pattern of sclerites in the early ontogeny of the holothurian. The simple rod is the most primitive type, the anchor and anchor plate being perhaps the most complex. Wheels are advanced structures, but precede the anchor and anchor-plate sclerites both chronologically and in the ontogeny of certain highly evolved Recent holothurians.

A synopsis of the new classification, showing nine families, twenty-five genera, and 128 species, is as follows (family names will be given in our forthcoming monograph: Frizzell and Exline, in press):

Family 1: Simple and multiradiate rods, curved or straight, ends often modified. Seven genera and twenty-two species.

Family 2: Perforated plates, single or multilayered, without socket or spire. Five genera and twenty-seven species.

Family 3: Imperforate disks and buttons, type genus with pseudospire. One genus and one species.

Family 4: Eyed hooks. One genus and nine species.

Family 5: Lyre-shaped sclerites. One genus and one species.

Family 6: Tables, with perforate disk and raised spire. One genus and sixteen species.

Family 7: Sclerites in the shape of wheels. Six genera and thirty-six species.

Family 8: Oval perforate plates (anchor plates), typically with socket. One genus and ten species.

Family 9: Double- or triple-fluked anchors. Two genera and six species.

The new classification has several advantages over arrangements previously proposed. It takes into account all published records that we have been able to evaluate, and provides a taxonomic structure for future modification to fit new discoveries. It supplies a nomenclatural system for taxonomic studies and for recording the data of biostratigraphy and paleoecology. The classification is preferable to the "ordo militaris" in conforming to an established and widely accepted legalistic code, the International Rules of Zoological Nomenclature, so that stability and uniformity should be promoted by its use. It is, however, compatible with most of the non-Linnean schemes that have been proposed, and could be transferred to any other binominal system without change, if withdrawal from the Linnean arrangement should prove desirable. Moreover, fossilized complete holothurians are so rare that there is no possibility of confusion between the zoological classification and the micropaleontological classification based on sclerites alone.

STRATIGRAPHIC RELATIONSHIPS

The stratigraphic relationships of holothurian sclerites are as yet little known, because of the relatively very minor amount of work that has been done on these microfossils. Some generalizations, however, may be made, especially when unpublished information is taken into consideration.

Three characteristic faunal assemblages are obvious—those of the Carboniferous, Jurassic, and Cretaceous-Cenozoic. The presumed Ordovician forms are open to question, the Devonian fauna is extremely sparse, and the sclerites of the Permian-Triassic interval apparently are transitional.

From evidence available, the Carboniferous and Jurassic periods seem to have been times of rapid evolution of holothurians, with the introduction of sclerites of new pattern. Only five types of sclerites seem to have been abandoned after their introduction, but three of these are unknown after the Jurassic period. Apparently, therefore, the Jurassic was a significant time in the evolution of holothurians, both in the origin of new forms and in the extinction or modification of the old.

A summary of records of holothurian sclerites, in the various systems, is as follows:

Ordovician

The earliest occurrence of presumed sieve plates is in the Middle Ordovician, where two species have been recorded. These may be plates of embryonic crinoids, however, and are not associated with sclerites of unquestionable holothurian origin. Consequently, the important question of the first appearance of holothurians is not satisfactorily solved by their discovery.

Devonian

Three genera and species, belonging to three families, have been reported from the Devonian. Two genera appear for the first time, only one of which is unequivocally holothurian.

Carboniferous

Twenty-three Carboniferous species, belonging to eight genera and five families, are known. Two genera begin in this system, and three are restricted to it. Some Carboniferous species are unusually long-ranging, as *Protocaudina traquairii* (Etheridge), from Mississippian to Permian, and *Protocaudina kansasensis* (Hanna), from Pennsylvanian to Permian.

Permian

The Permian contains a very sparse fauna consisting of six species, belonging to four genera and three families. A single new genus appeared, restricted to the Permian, and one genus had its last occurrence.

Triassic

Only five species, belonging to four genera and four families, are known from the Triassic. One genus appeared for the first time, and another is restricted to the system.

Jurassic

As already noted, the fauna of the Jurassic is conspicuous and varied, and in consequence has received a considerable amount of study. It contains fifty-two known species, belonging to eighteen genera and seven families. Ten genera appeared for the first time, three became extinct, and two are restricted.

Cretaceous

Virtually no work has been published on Cretaceous sclerites, although our collections show a wide variety of forms to be present. Three named species, belonging to three genera and two families, are recognized. Curiously, two of these were published with misidentifications, one having been mistaken for a diatom and the other for a foraminiferan.

Paleocene

A single record of Paleocene sclerites has been found, from the Midway group of Alabama. These anchors and anchor plates apparently belong to undescribed species.

Eocene

The Eocene has yielded an extensive sclerite fauna, although almost entirely from a single locality in France. Thirty-one species, belonging to eight genera and five families, are known.

Oligocene

The faunas of the Oligocene are virtually unstudied, but six species, belonging to four genera and three families, have been reported. One genus is restricted.

Miocene

Miocene sclerites have been mentioned in publication, with three Recent holothurian genera questionably identified. The evidently varied sclerite fauna, however, seems to have received no critical study.

Pliocene-Pleistocene

A single Pliocene form, identified with a Recent species of holothurian, has been recorded. Similarly, two Recent holothurian species have been identified from Pleistocene sclerites.

The practical application of holothurian sclerites to correlation has been of minor importance, although they have been used in local correlation in the Carboniferous of the United States and the Jurassic of Central Europe, and are said to have been used in the Cretaceous of North Africa and the Cenozoic of northern South America. Probably the greatest hindrances to correlation with the aid of sclerites are their scarcity and extremely delicate structure. Even where sclerites occur commonly in microfossil samples, their use has been largely forestalled by the lack of an adequate system of classification and nomenclature. With a unified taxonomic scheme, and after extended studies of the faunas of various systems and formations, holothurian remains offer a potential tool for use in correlation.

PALEOECOLOGY

A second possible application of research on holothurian sclerites is in the field of paleoecology. Holothurian remains have been found most frequently in clays, marls, shales, and sandy shales. Records from limestones and marly limestones are less common, and reported occurrences are rare in sandstones, greensand, and in a matrix of fine organic debris. Many of the sclerites, as should be expected from their habitat, belonged to apodous forms that burrowed in mud. Both the relative abundance of burrowing forms

and the preponderance of occurrences in fine-grained sediments, however, probably are due in large part to selective search by micropaleontologists, who usually have ignored the coarser materials.

The environment of fossil holothurians is marine and tropical to sub-Arctic. Bathymetric range is littoral to moderately deep, with very rare occurrence in deep-sea deposits, most of the sclerites at considerable depths presumably having been dissolved shortly after deposition. Fossil sclerites occur in various faunal assemblages, but are most consistently associated with fragmental remains of other echinoderms.

Holothurians live in three general habitats — as free-moving organisms on rock or sand bottom and reefs, as burrowing forms within the substratum, and extremely rarely in the pelagic state. The first two of these modes of life are believed to have been followed as long as holothurians have existed. Attempts to interpret the preferences and tolerances of these organisms, for the various environmental factors affecting water and substratum, challenge the ingenuity of the paleoecologist.

Paleoecology involves a basic problem quite different from those of ecology, that of resolving the environmental complex of fossil assemblages. The material of paleoecology consists of *thanatocoenoses,* or death and burial associations, as opposed to the ecological *biocoenoses,* with their unified assemblages of organisms that live together. A thanatocoenosis consists of a mixture of biocoenotic elements within a given radius of deposition. It may contain material introduced by current action from adjacent depositional areas, but endemic material may have been carried away and deposited elsewhere. The entire thanatocoenosis, in fact, may consist of transported and mixed elements, none of which was endemic to the place of final deposition. The resolution of thanatocoenoses into bionomic cross sections therefore presents a peculiarly complex problem.

Most workers on fossil remains seem tacitly to have assumed an endemic position for holothurians in the thanatocoenoses in which the sclerites occur.Moreover, some authorities have found a definite correlation between sclerite type and depositional facies. Thus Spandel (1898) reported a hook-shaped sclerite from both reef facies and stratified beds in the Permian of Germany, whereas wheels and lyres are restricted to the reef facies. Similarly, Kuhn (1935) showed the bionomic position of another wheel in the benthonic fraction of a Jurassic thanatocoenosis that included a mixture of plankton, nekton, and benthos.

Some instances of presumed transportation of holothurian remains have been postulated. Broili (1926), dealing with the Jurassic Solenhofen limestone, considered that a complete individual had been carried into place by current action, having lived in muddy sand or on a coral reef. Davis (1936) suggested a similar redeposition in shallow water to explain the occurrence of a wheel-shaped sclerite in the Eocene London clay. He regarded holothurians of the type bearing this sclerite as inhabiting "blue muddy bottoms" rather than the shallower sediments in which the sclerites were found. Similar forms, however, live in the littoral zone on the California coast.

Holothurian remains can be transported in two ways, either as complete dead individuals or as dissociated sclerites. Dead individuals may be carried along the sea bottom by current action or, especially in the case of material that has been sun-dried in the intertidal zone, as floating pseudoplankton. They may be transported seaward or shoreward. In either case, burial of the complete individual would result in a normal association of sclerites that would be virtually impossible to distinguish from sclerites of an individual that was buried in place. Dissociated sclerites, in contrast, would be carried as elements of the sediment, usually seaward. Their final point of deposition would depend upon their effective particle size and specific gravity, taking into consideration shape and surface area, and in general would be in deeper water than that in which the animal lived. Their distribution would be independent of their systematic and ecological relationships.

Available evidence, both in literature and from our observations, suggests that fossil sclerites usually were deposited in, or relatively close to, the environment in which they lived. The associated assemblages, especially of other echinoderms, are consistent. Moreover, apodous forms occur in marls and shales, forms with tube-feet having been recorded from coarser sediments. Much more research is needed, however, before the endemic nature of holothurian sclerites can be accepted without qualification.

Another paleoecological factor is the effect of the substratum. Holothurians burrow into the bottom or crawl upon it, or cling to rocks and seaweed. Although the apodous forms typically are burrowing, pedate species differ widely in choice of habitat. Consequently, only a generalized interpretation of substratal relationships may be made from the presence of sclerites in a rock unit: Hooks, anchor plates, anchors, wheels, and some rods represent burrowing apodous forms, usually in a muddy substratum; rods,

plates, disks, lyres, and tables represent holothurians of uncertain habit, burrowing, crawling on, or partly submerged in the substratum, or clinging to rocks and seaweed.

Salinity is a controlling factor in the distribution of holothurians, fossil sclerites being indicative of normally saline water. Only two Recent species are known to live in brackish water, one in northern and one in tropical latitudes, and this habitat seems to have been entered in very late geologic time.

Holothurian sclerites have a limited application as indices to temperature in Cenozoic strata, but, from our present knowledge, are relatively useless in older rocks. Sclerite assemblages may show thermal relationships, such as that of the Burdigalian Miocene of France to the Recent assemblage of Senegal, or that of the Pleistocene *Yoldia* clay of Denmark to the Recent boreal fauna of the North Atlantic. More extended interpretations, however, are unsafe. In addition, some species are stenothermal and eurybathyal, living in very shallow water at polar latitudes and at progressively greater depths nearer the equator.

Some factors limiting the usefulness of holothurian sclerites as temperature indicators are the impossibility of associating many forms with Recent genera, families, and even orders; the range of thermal tolerance within known analogues of Recent families and genera; the depth-temperature correlation in some species; and the possibility that extinct analogues of Recent forms had different ecological adjustment.

The depth at which sediments were deposited may also be inferred, to some extent, from holothurian remains. Fossil sclerites are restricted almost entirely to deposits of shallow to moderate depth. Although sea-cucumbers are abundant and varied in the depths of the sea, being especially numerous on bottoms of red clay, *Globigerina* ooze, and diatom ooze, their sclerites are scarce in deep-sea sediments. Bramlette and Bradley (1941) have suggested that sclerites disappear by solution shortly after death of the containing organism. Thus, out of eleven cores of Pleistocene deep-sea deposits from the North Atlantic described by Henbest (1942), only a single sample showed the presence of sclerites. In general, depth relationships of fossil sclerites have been inferred from the known ecological restrictions of associated assemblages, and present knowledge does not permit the extensive use of sclerites as direct bathymetric indices.

Holothurian sclerites usually are associated with the remains of other organisms of the littoral and neritic zones. Some of the more typical of these are mollusks, fragments of other echinoderms such as echinoids, asteroids, ophiuroids and crinoids, foraminifera, ostracodes, and the teeth, scales, and otoliths of fish, and sometimes with bryozoans, corals, sponge spicules, and brachiopods. Although no complete paleoecological census seems to have been recorded for any formation, a number of representative assemblages have been reported.

A sublittoral association from the cold-water Pleistocene beds of Denmark contains holothurian plates associated with several pelecypod species, a gastropod, and an ophiuroid. Another sublittoral occurrence, in the Oligocene rocks of the Mainz Basin of Germany, shows anchors and anchor plates in association with foraminifera, ostracodes, and mollusks. The assemblage apparently is indicative of water from three to six meters in depth.

Assemblages of the neritic zone have been described by a number of authors from Jurassic strata of Europe and North Africa, and from the Cretaceous of Central Europe. Kuhn (1935) has given a comprehensive list of fossils associated with holothurian wheels in the so-called sponge facies of the zone of *Cardioceras alternans* of the Jurassic that is fairly representative for the neritic zone. Included are ninety-seven species of foraminifera, sixty-three species of sponges, twenty species of echinoderms (asteroids, crinoids, and echinoids), eight species of bryozoans, seven species of worms, eight species of pelecypods, four species of gastropods, twenty-nine species of cephalopods, and some crustaceans (including ostracodes).

Deep-sea occurrences are extremely rare. A single Pleistocene sample from the North Atlantic recorded by Henbest (1942) contained sclerites associated with common pelagic and sparse benthonic foraminifera.

SUMMARY

The present status of the micropaleontology of holothurian sclerites may be summarized very briefly:

A monograph of fossil sclerites (Frizzell and Exline, in press) includes a new classification with nine families, twenty-five genera, and 128 species. Although the classification is in a sense artificial, it is proposed within the framework of the International Rules of Zoological Nomenclature.

Holothurian sclerites are potentially useful as stratigraphic markers, especially where, as in Jurassic and Carboniferous rocks, these microfossils are relatively common and conspicuous.

Although a great deal remains to be done in establishing the paleoecological relationships of fossil holothurians, it seems that these organisms may be of value in drawing ecological conclusions, especially when considered in the light of associated assemblages.

This paper was read in slightly abbreviated form during a symposium on spores, pollen and other microfossils useful in oil exploration sponsored by the Society of Economic Paleontologists and Mineralogists, held at New York March 30, 1955. The accompanying illustrations were redrawn by John W. Koenig, of the Missouri Geological Survey, Rolla, Missouri, from copies of published figures. We are indebted to Dr. W. S. Hoffmeister, of The Carter Oil Company, Tulsa, Oklahoma, for assembly of the figures.

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ABSTRACT: *Certain Paleozoic oil-bearing rocks—boghead coals or torbanites, and others—derive their oil content from the hydrocarbon-producing alga* Botryococcus. *The same genus produces fatty sediments in modern brackish and fresh-water lakes. It has seemed likely that the organism was important in the Cenozoic also. The appearance is noted here of a number of recently reported Tertiary records of* Botryococcus *in India and Australia, and the first American Tertiary record, in the organic silt overlying the Brandon lignite, Vermont, is described.* Botryococcus *microfossils from the Warlands Creek locality, Australia, are very closely comparable to those from Brandon.*

Occurrence of the oil-forming alga Botryococcus in lignites and other Tertiary sediments

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INTRODUCTION

The importance of certain algae in the sedimentation of various organic rocks was recognized as long ago as the 1880's and 1890's. David (1890) suggested in an addendum to his paper on the origin of Australian kerosene shale (torbanite) that ". . . it may be found that these spherical bodies are to be referred to some variety of fresh-water alga. . . ." C. E. Bertrand (1893) and Renault (1899) carried the suggestion of David one step further with a systematic microscopic examination of European, Australian and American boghead coals. They proved that colonies of algae made up the bulk of the substance of boghead coals, and they established the genera *Pila* and *Reinschia* for these algae. They believed that the alga they named *Reinschia,* typical of the Australian torbanites or bogheads, is distinct from the alga typical of bogheads from the Northern Hemisphere. Subsequent investigations by Zalessky (1926) and by Thiessen (1925) showed clearly that the causal alga in boghead coals was a close relative of, if not identical with, *Botryococcus braunii* Kützing, an extant alga that produces quantities of fatty and waxy matter. The key to the identity of the form was, for both Zalessky and Thiessen, the nature of contemporary sediments formed by *B. braunii.* Zalessky studied paraffin-like material (balkhashite) produced by *B. braunii* in Russian lakes, and Thiessen investigated similar material, the so-called coorongite, formed in salt lakes and lagoons of the Coorong region of Australia. Zalessky first noted the identity of the causal organism of these modern hydrocarbon-rich sediments, although Chodat (1896, p. 337) laid the groundwork for this discovery when, in his study of the modern alga, he wrote: ". . . les *Botryococcus* s'accumulent à la surface et s'y maintiennent même après leur mort . . . . il est donc hors de doute que l'huile est excrétée par les *Botryococcus.* . . ." To Thiessen must go much of the credit for proving that boghead coals and similar materials derive to a greater or lesser extent from the activities of algae closely related to *Botryococcus,* and that coorongite is the peat-stage equivalent of torbanites and boghead coals.

Subsequently, P. Bertrand (1927, 1930) reinvestigated the boghead coals and torbanites studied by Renault and C. E. Bertrand forty years earlier. He confirmed the findings of Thiessen, and agreed that the alga formerly designated *Pila* is certainly *Botryococcus.* He maintained that the former *Reinschia,* however, is a distinct form of alga. Then Blackburn and Temperley (1936) published a thorough investigation of the morphology of the modern *Botryococcus braunii,* as related to the fossil algae of boghead coals, torbanites and related oil-bearing rocks. They proved that all of these fossil forms are at least closely related to *B. braunii.* Frémy and Dangeard (1938) reported another detailed study of extant *Botryococcus* algae from a Swedish lake and of the abundant fossil

algae in a Tertiary black clay of France, showing beyond doubt that the fossil algae are *Botryococcus*.

Dulhunty (1944) studied the Australian Permian torbanites thoroughly and has used the occurrence of these algal coals to deduce paleogeographic information about Australian coal fields, assuming that occurrence of *Botryococcus* indicates relatively humus-free lakes in the marginal areas of the coal-forming basin. He has also shown the relationship of the algal nature of these torbanites or boghead coals to their sedimentation and to subsequent coalification. Similarly, Schopf (1952, p. 318) records the opinion that association of *Botryococcus* fossils with the coal-petrographic component, opaque attritus, permits the deduction that the petrographic component was not formed under dry conditons, as has often been argued. It now seems fair to assume that the oil content of these organic rocks is in fact due to *Botryococcus*, either as hydrocarbon-rich matter in the fossil algae themselves or as similar matter derived from decomposition of the algae.

The Paleozoic boghead coals and torbanites have been the subject of two lively controversies, each of which has played a part in their rather thorough study. First there was the well-known squabble in the mid-Nineteenth Century British courts over the nature of certain Scottish bogheads—whether or not they are coal. Then, in the first quarter of the present century, the prolonged scientific controversy developed between Renault, the two Bertrands, and latterly others on one side, and E. C. Jeffrey on the other. C. E. Bertrand and Renault had recognized the algal nature of the dominant microfossils in the bogheads, but Jeffrey (1909, 1910, 1924) held that these fossils were predominantly spores. Zalessky's, Thiessen's, and P. Bertrand's work clearly showed that the disputed substances are of algal origin, and effectively closed the controversy.

In North America there are many oil-bearing rocks of various ages that have not been thoroughly investigated by modern microscopic techniques. Some of these may well prove to owe their hydrocarbon content to fat- and oil-producing algae of the *Botryococcus* series, or perhaps to related algae. The important Eocene Green River oil shale of the Rocky Mountain region, however, is not botryococcoid. This is clear from the work of Bradley (1924, 1931) and remarks of Schopf (1952, p. 111).

In this connection, it is of great interest that fifty years ago David White wrote of the Ordovician Galena oil shale in Illinois as follows:

> "Thin sections . . . contain minute, flattened, generally oval, and discoid translucent bodies of a brilliantly lemon-yellow color and highly refractive. . . . These yellow bodies, varying from 8 to 62 microns in horizontal diameter and 5 to 20 microns in vertical, usually thinly lenticular and irregularly rounded at the edges, but often nearly oval . . . are incredibly numerous, constituting over 90 per cent of the rock mass in the richest layers. . . .
>
> "The yellow bodies are therefore interpreted as the fossil remains of microscopic, unicellular, gelosic algae, apparently comparable to the living Protococcales. . . .
>
> "The oil shales owe their volatile hydrocarbon contents either directly or indirectly to the fossilized residues, interpreted as the remains of microscopic algae, which locally composed over 90 per cent of the sedimentary material."

This description certainly is very suggestive of a member of the *Botryococcus* group.

Also significant is W. H. Bradley's (1924) work on the oil shale of the Lower Cretaceous Fuson formation. He wrote: "Probably the most important organism as a producer of oil . . . is the fatty alga *Epipolaia corymbus*. The writer has calculated that there are about three hundred thousand algae per cubic centimeter. . . . *Epipolaia corymbus* is also very similar in its size, form, and radial structure to the living genus *Botryococcus*. . . ." Bradley's illustrations convince this writer that the Fuson algae are indeed *Botryococcus*.

PRE-CENOZOIC RECORDS OF BOTRYOCOCCUS

The majority of former studies of organic algal sediments have treated Paleozoic deposits. There is abundant evidence of Mississippian, Pennsylvanian, and Permian rocks rich in *Botryococcus*, such as the boghead coals or torbanites, certain algal shales, and the like.

Some published illustrations of microfossil colonial algae show striking resemblance to *Botryococcus*, and some of these plants will probably prove to be closely related or even generically identical to *Botryococcus*—for example, such forms as certain of the *Gloeocapsomorpha* series. Illustrations of the *Gloeocapsomorpha* composing the basic substances of the kuckersite of Estonia suggest possible relationship with *Botryococcus*. Kuckersite is composed of masses of the alga, associated with abundant brachiopod shells. The age of the sediment is Ordovician. Harris (1938) reduces this *Gloeocapsomorpha* (*G. prisca* Zal.) to synonomy with *Botryococcus braunii* Kützing. This

record, and White's record of fossil algae from the Galena rocks, indicate that *Botryococcus* probably extends back at least to the Ordovician.

Harris (1938) describes a Triassic occurrence in England and also states that several species of *Pila* described from the Jurassic can be regarded as *Botryococcus*. Bradley's (1924) work on the Lakota and Fuson formations provides a Cretaceous record.

POST-CENOZOIC RECORDS OF BOTRYOCOCCUS

The occurrence of *Botryococcus* in a number of Pleistocene sediments has been recorded. Jessen and Milthers (1928), for example, reported *Botryococcus* from many of the fresh-water interglacial muds and peats of Jutland and northwestern Germany. Raistrick and Blackburn (1932) noted that *Botryococcus* fossils are present in deep lowland peats of the North Pennines, England. Cookson (1953) records several Pleistocene occurrences in Australian peat and clay.

The formation of coorongite, balkhashite, and similar hydrocarbon-rich sediments produced by *Botryococcus* in modern fresh-water and brackish lakes indicates the continuing importance of this alga in sapropel-producing sedimentary situations. Naumann (1922), in his classification of fresh-water sediments, lists these algal deposits under resistant sediments, as the "Chlorophyceae-type, characterized by presence of entire *Botryococcus* colonies."

This would appear to be a most striking example of generic persistence. As only vegetative reproduction has so far been noted, Blackburn (1936) has suggested the possibility that *Botryococcus* may have reproduced continuously since mid-Paleozoic times by vegetative division. Dulhunty (1944, p. 32) also comments on this generic persistence: ". . . that organic evolution should have allowed the organism to remain almost unchanged over the immense length of time . . . is extraordinary. . . . The very primitive nature of the living *Botryococcus* suggests that the organism has not changed for a very long time, and . . . has descended from the late Paleozoic alga . . . without appreciable modification."

PREVIOUS CENOZOIC RECORDS OF BOTRYOCOCCUS

Reports of *Botryococcus* in Tertiary sediments have been rare until the last few years. Harris (1938) lists an Oligocene occurrence of *Botryococcites*, described by Bertrand in 1898. This is presumably a *Botryococcus* record. Bradley's (1924) *Epipolaia corymbus* is with very little doubt a Lower Cretaceous record, and there are probably Tertiary occurrences masquerading under synonyms as well. Frémy and Dangeard (1938) listed Tertiary occurrences of *Botryococcus* in two black clays and one "bituminous schist" in France.

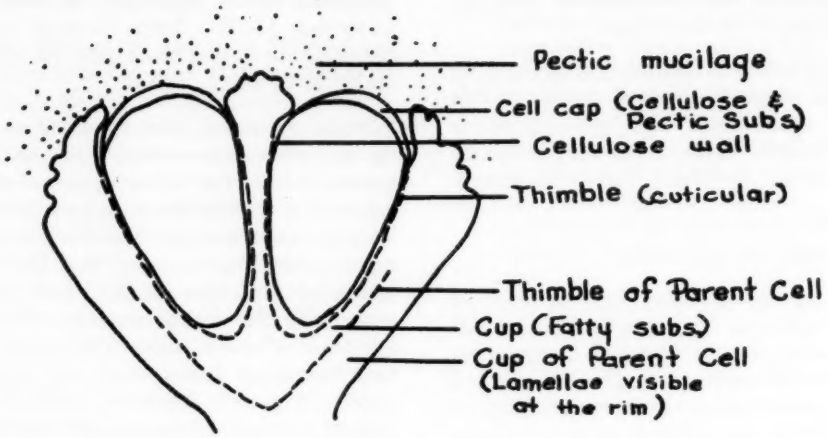
Within the last five years a number of occurrences of the genus have been recorded for the Cenozoic era—a demonstration that sedimentation of organic material has continued along the same general lines for a very long period of geologic time. Rao and Misra (1949) report *Botryococcus* from the Eocene(?) Palana lignite of Rajputana, India. Vimal (1953) has described abundant *Botryococcus* from the Eocene Cutch lignite of Western India. This lignite is composed very largely of *Botryococcus* and appears to be a lignitic boghead. Edwards (1953, p. 51), in his general treatment of brown coals, writes that *Botryococcus* occurs in dysodile-like Tertiary lignitic clays of Australia. Cookson (1953) has reported investigations of a number of Australian Tertiary sediments containing *Botryococcus* fossils. The sediments range in age from Oligocene to Pliocene, and include carbonaceous clays, carbonaceous sandstone, carbonaceous shales, and lignite. Ingwersen (1954) found *Botryococcus* in the lowest part of the late Tertiary lignite bed at Bjerregårde, Jutland, Denmark, and states that Lagerheim found the microfossil in lignite gyttja of East Jutland about fifty years ago.

OCCURRENCE OF BOTRYOCOCCUS IN THE BRANDON FORMATION

The small deposit of lignite near Forestdale in the town of Brandon, Vermont, is associated with other sediments, including clays and an overlying organic silt. The whole formation is believed to represent a rather short time-interval and has been dated as Lower Tertiary, probably Oligocene, on paleobotanic evidence.

The microfossil flora of the overlying silt shows enough continuity with that of the lignite proper to indicate that the silt is part of the same depositional sequence, as previously reported by Traverse and Barghoorn (1953). Several significant differences have been noted, however. The silt is lacking in pollen of the swamp shrub *Cyrilla*, a very abundant constituent of the microfossil flora of the lignite. Several microfossils absent in the lignite are important in the silt. One of these is *Botryococcus*.

After oak pollen-grains, *Botryococcus* colonies are the most abundant constituents of the microfossil flora of the silt. The abundance of *Botryococcus*


Pectic mucilage
Cell cap (Cellulose & Pectic Subs)
Cellulose wall
Thimble (cuticular)
Thimble of Parent Cell
Cup (Fatty subs)
Cup of Parent Cell (Lamellae visible at the rim)

TEXT-FIGURE 1

Diagram from Blackburn (1936), showing schematically the arrangement of a pair of cells in a colony of *Botryococcus braunii* Kützing, × ca. 7000. Fossil colonies of *Botryococcus* lack the cell, cell cap, cell wall, and mucilage shown here.

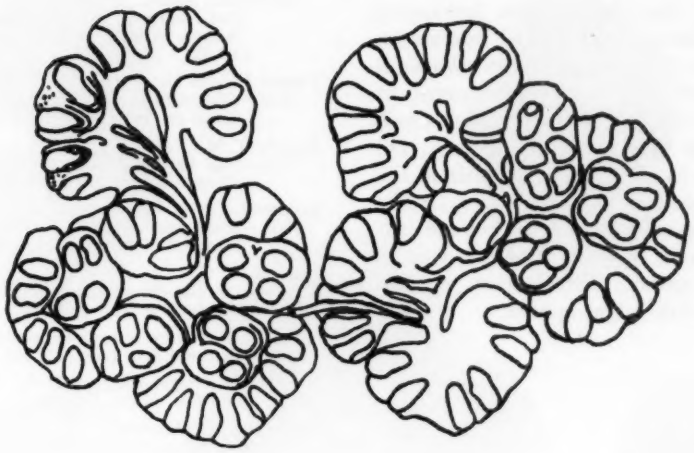
colonies and *Quercus* pollen, together with the occurrence of fossil dinoflagellates in the silt, is interpreted to mean deposition in shallow, rather muddy, but open water, some distance from standing vegetation; hence, the dominance of pollen of the anemophilous oak over other pollen types. *Botryococcus* fits in well with this picture of the depositional origin of the Brandon silt.

This interpretation of the origin of the silt agrees well with previous observations on *Botryococcus*-rich sediments. Jessen and Milthers (1928), in their work on Pleistocene sediments, found *Botryococcus* mostly in brown argillaceous muds, although the microfossils were also noted in peat and in sandy muds. Raistrick and Blackburn (1932, p. 98) write of the occurrence of *Botryococcus, Pediastrum* and pollen in deep lowland peat: "Taken together these records seem to indicate the shallow margin of a mere with neutral or alkaline water. . . ." Bradley (1924) wrote of the Fuson oil shale: "Judging from the habitat of the living genus *Botryococcus*, . . . it is highly probable that the . . . shale was deposited in small, quiet, open ponds of fresh water. . . ." Dulhunty (1944, p. 37) deduced that botryococcoid deposits do not form in peaty swamps in which the water contains considerable humic matter—the alga does not make a rich growth under such conditions. He felt that vigorous sedimentation is characteristic of basins in which deposits containing abundant *Botryococcus* fossils are formed, and stated: ". . . the deposits were formed in small, isolated lakes, filled by the penetration of backwaters through peat beds or marshes from flowing watercourses some distance away."

COMPARISON OF BOTRYOCOCCUS FROM THE BRANDON SILT WITH THOSE FROM AN AUSTRALIAN CARBONACEOUS CLAY

For comparison with the Brandon material, Dr. Isabel C. Cookson, of the Botany School, University of Melbourne, Australia, kindly sent the author slides of *Botryococcus* prepared from a carbonaceous clay of presumed Oligocene-Miocene age from Warlands Creek, New South Wales, Australia. Examination of this material shows that the Australian Tertiary *Botryococcus* and that of the Brandon formation are very much alike and are unquestionably generically identical.

As may be seen in text-figure 1, the fundamental structural unit of a *Botryococcus* colony is a cell with a cellulosic wall partly enclosed within a conical or egg-shaped chamber. The immediate walls of this chamber are a product of the cell itself. The structure so produced, in which the cell is seated, is termed the thimble. According to Blackburn, this thimble is cuticular and waxy. Enclosing the thimble is a larger structure, the cup, also produced by the cell. This cup is fatty. The colony grows by division of the cells along the longitudinal axis. The daughter cells then form new thimbles and cups within the old. Hence, as



TEXT-FIGURE 2

Drawing from Blackburn (1936), showing outline form of a living compound colony of *Botryococcus braunii* Kützing, × ca. 1470.

more divisions take place, a complex colony is built up, with the cells usually grouped in twos and fours. The thimbles and cups of the parent cells remain in the colony, even after many divisions, and form the matrix of the colony below the chambers in which the living cells are located. The grouping of the cells in multiples of two in a more or less dichotomous arrangement is distinctive, as is the waxy-fatty skeleton of the colony. The cells of the colonies may be grouped compactly (text-fig. 2; pl. 1, figs. 3, 8, 9) or may be rather openly branched (pl. 1, fig. 7). On the basis of this colonial organization, the nature of the chloroplast, and the nature of the cell secretions, Blackburn (1936) put *Botryococcus* in the colonial Chlorococcales. Text-figure 2 shows a colony as seen in outline in a microscopic preparation. The illustrated colony is compound, with a tongue of the colonial matrix joining the parts. This is also a common feature of fossil *Botryococcus* colonies. (Compare pl. 1, figs. 4 and 8.)

When deposited in an organic sediment, the cells themselves are ordinarily destroyed. Fossil *Botryococcus* colonies consist of the waxy-fatty skeletons of the colonies, or these skeletons as modified by the processes of sedimentation and coalification. The fundamental structure of the colonies is well preserved in the fossils and is obviously chemically resistant. The fossil *Botryococcus* colonies from the Brandon silt that are described and illustrated here survived demineralization of the silt with HF, maceration in 10% KOH, bleaching with 5-7% $NaClO_2$ in dilute HCl, and acetylation in a hot 9:1 mixture of acetic anhydride and concentrated H_2SO_4, before mounting in glycerin jelly.

Plate 1, figures 1 to 4, show *Botryococcus* fossils isolated by Dr. Cookson from the Warlands Creek clay in Australia. Figure 1 shows the grouping of the waxy-fatty chambers in twos and fours in a small colony. Figure 2 is a medium-sized colony with two centers of cell division—a divided colony in the making. Figure 3 illustrates a more compact colony. Figure 4 shows a divided colony, the two parts held together by a tongue of matrix, as in text-figure 2.

Plate 1, figures 5 to 9, illustrate *Botryococcus* fossils from maceration preparations of the Brandon silt. Figures 5 and 6 are surface views of small colonies, showing several groups of four cells in the typical *Botryococcus* configuration. Figure 7 is a surface view of a larger colony with a rather loosely branched organization. The arrangement of cells in twos and fours is also apparent here. Figure 8 illustrates a compact but compound colony in which the two parts are joined only by a tongue of matrix (old cups and thimbles), as illustrated in text-figure 2. Figure 9 shows the denseness of a rather large colony.

The cells in the Australian material tend to be oval in cross section, while those of the Brandon fossils are more nearly circular. The Australian material has somewhat larger cells (averaging about 9 microns

in maximum cross-sectional diameter and 10 microns on the vertical axis) than the Brandon (averaging about 6 microns in diameter and about 8 microns on the vertical axis). The morphology of the colonies is strikingly similar, with about the same range of structure in each. Unquestionably, the Warlands Creek fossils and those from Brandon are congeneric. Dr. Cookson has put the Warlands Creek fossils in the extant species *Botryococcus braunii* Kützing. If the Brandon material is similarly treated, the two are conspecific. The author feels, however, that it is wise to be cautious about specific identification of pre-Pleistocene material with extant species.

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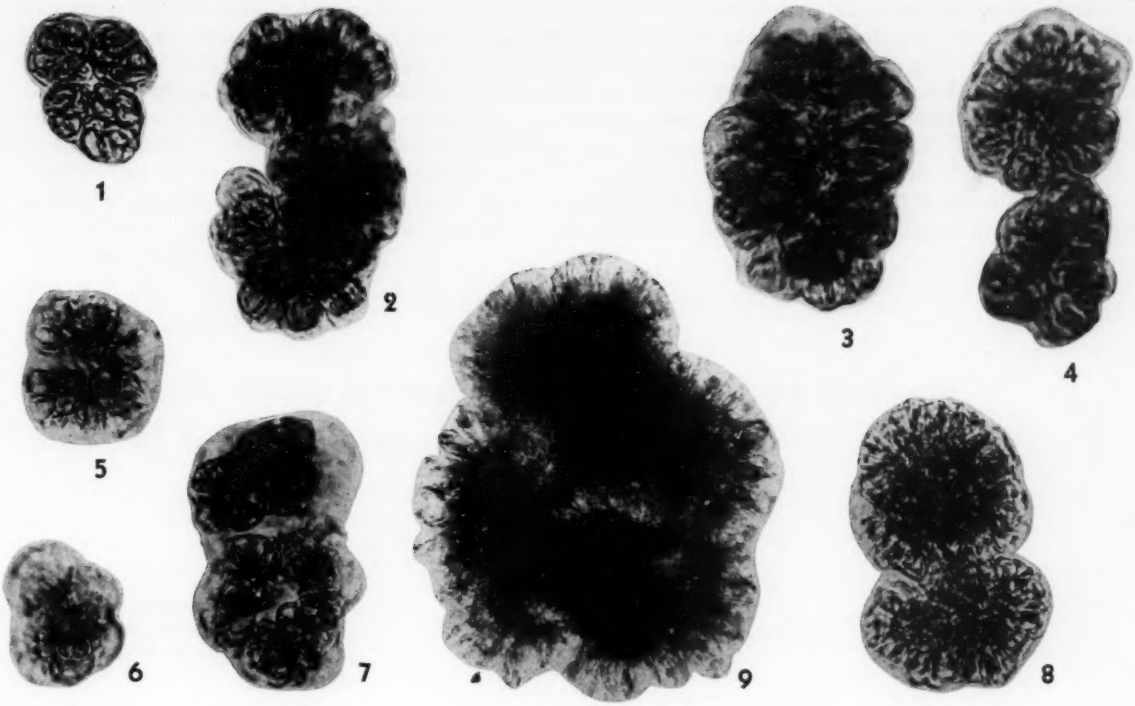

EXPLANATION OF PLATE 1

Cenozoic *Botryococcus* colonies from New South Wales, Australia, and Brandon, Vermont.

1 Small colony from Warlands Creek clay (Oligocene-Miocene?), New South Wales, Australia. Surface focus, showing arrangement of cell-chambers in pairs and fours. Maximum dimension: ca. 36 microns. × ca. 675.

2 Medium-sized colony from Warlands Creek clay (Oligocene-Miocene?), New South Wales, Australia. Incipient division of colony shown. High mid-focus. Maximum dimension: ca. 77 microns. × ca. 675.

3 Medium-sized compact colony from Warlands Creek clay (Oligocene-Miocene?), New South Wales, Australia. Mid-focus. Maximum dimension: ca. 70 microns. × ca. 675.

4 Medium-sized divided colony, the parts connected by a strand of matrix. (Compare with text-fig. 2 and pl. 1, fig. 8.) From Warlands Creek clay (Oligocene-Miocene?), New South Wales, Australia. Mid-focus. Maximum dimension: ca. 74 microns. × ca. 675.

5 Small colony from Brandon silt (Oligocene?), Vermont. High focus, showing typical grouping of cell-chambers in surface view. Maximum dimension: ca. 35 microns. × ca. 675.

6 Small, somewhat eroded colony from Brandon silt (Oligocene?), Vermont. High focus, to show typical grouping of four cell-chambers. Maximum dimension: ca. 31 microns. × ca. 675.

7 Medium-sized colony from Brandon silt (Oligocene?), Vermont. High focus, showing relatively loose branching, and the arrangement of the cells in two and fours. Maximum dimension: ca. 65 microns. × ca. 675.

8 Compound, compact colony from Brandon silt (Oligocene?), Vermont. Mid-focus, showing the divided nature of the colony. The two parts of the colony are connected by a strand of matrix. (Compare with text-fig. 2 and pl. 1, fig. 4.) Maximum dimension: ca. 80 microns. × ca. 600.

9 Large colony from Brandon silt (Oligocene?), Vermont. Mid-focus, showing the denseness of the colony. Maximum dimension: ca. 96 microns. × ca. 675.

ABSTRACT: *Methods employed for routine laboratory culture of foraminifera are described and some preliminary experiments concerning the effects of food, temperature and salinity upon the population growth are discussed. Populations of* Rotaliella heterocaryotica *Grell have been found to eat dead flagellate cells* (Chlamydomonas) *and living diatoms* (Nitzchia). *Populations of* Rotaliella *sp. do not appear to utilize dead* Chlamydomonas *and will die unless living* Nitzchia *or its equivalent is provided. Temperatures of 14.5° C. result in a lower rate of growth for* Rotaliella heterocaryotica *and* Rotaliella *sp. than do room temperatures of 22.2° C. and 24.5° C. Data from salinity experiments on* Rotaliella heterocaryotica *suggest the following: There is no significant population growth at salinities less than approximately 25‰; population growth occurs at salinities above 25‰ with the optimal salinity apparently between 26 and 30‰; no consistent population growth occurs at salinities above approximately 37‰.*

Preliminary laboratory experiments on ecology of foraminiferal populations*

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INTRODUCTION

In the study of populations of foraminifera, numerous problems arise that are difficult to answer by field studies alone. Underlying causes affecting distribution may be so complex that the correlation of the usual ecologic factors (e.g., temperature, salinity, etc.) with observed distribution is only partially satisfactory. For example, the marked biofacies depth-boundary near the edge of the continental shelf has been attributed to the presence of a seasonal water-layer (Phleger, personal communication), which is subject to seasonal variations of temperature, salinity, light, food, etc. On the basis of field studies alone, however, it is difficult or impossible to determine which specific environmental factors are critical. If key species from above and below this biofacies depth-boundary could be cultured under controlled laboratory conditions, it might be possible to determine the relative importance of individual environmental factors. It may be possible to understand the effects of the numerous features of the marine environment on foraminifera by studying the physiological effect of single factors. After some understanding of single factors is gained, it should be possible to analyze the effects of combinations of factors.

Another important problem is the measurement of foraminiferal productivity, such as rates of growth and number of young produced per year. A knowledge of the rate of addition of empty tests of foraminifera to the sediments and of the conditions which affect this productivity are of primary interest in sedimentology. This problem and related ones may be partially answered by controlled population experiments. Various taxonomic problems, such as determination of specific ranges of morphological variation and correct identification of juvenile forms, could be simplified by study of laboratory cultures. Arnold (1954*a*) has illustrated this approach admirably in his study of variations in *Discorinopsis* cultures.

Many workers have cultured foraminifera in the laboratory, but it is only recently that more refined techniques have been used. Arnold (1954*b*) gives a brief historical summary of culture experiments on foraminifera in his paper on culture methods.

Preliminary work with cultures of benthonic foraminifera was started at the Marine Foraminifera Laboratory in the spring of 1954, as a part of long-range

*Contribution No. 22, Marine Foraminifera Laboratory; Contribution from the Scripps Institution of Oceanography, New Series, No. 806.

studies of foraminiferal ecology. The purposes of the present discussion are to describe the methods being used for the experimental culture of foraminifera, and to give the results of some preliminary laboratory experiments.

The work has been done under the direction of Fred B Phleger. Discussions with Zach M. Arnold have been of great value. Karl G. Grell, of the Max-Planck-Institut für Biologie, has aided greatly by suggesting culture techniques and procedures, and by furnishing cultures of *Rotaliella heterocaryotica* Grell, *Rotaliella* sp., and a marine species of *Chlamydomonas*. The studies have been supported in part by a contract of the University of California with the Office of Naval Research and in part by American Petroleum Institute Project 51.

METHODS

Suggestions for collecting shallow-water foraminifera made by Myers (1935) and more especially by Arnold (1954*b*) generally have been followed. Material has been transported to the laboratory in a thermos bottle kept slightly below the temperature of the original environment. If a small amount of organic material and a relatively large proportion of water are included, a considerable period of time may elapse before the samples are examined. Sediment samples from the Gulf of Mexico have been flown to La Jolla in thermos bottles, and the living foraminifera have appeared to be healthy upon arrival.

Arnold (1954*b*) has reviewed culture methods and has given suggestions on technique, particularly for intertidal forms. Special methods not required for some biological studies are necessary for controlled ecologic experiments, since all aspects of the environment should be known at all times. The culture should be free of other organisms which may influence the foraminifera. Associated animals may compete for the same food supply and may feed upon the reproductive products and upon the foraminifera themselves. Associated animals usually can be removed by repeated transfer of the specimens by pipette through several dishes of sterile sea water. In this way the larger unwanted organisms eventually will be eliminated, but specimens of foraminifera may still have micro-organisms attached to them; these are difficult to remove. Bacteria-free cultures are desirable, especially for critical nutrition studies, and an attempt should be made to make the culture as sterile as possible. Several methods have been devised for purifying other protozoans by use of antibiotics (Slater, 1955) and these techniques may prove useful in the present studies.

Pyrex custard-dishes with a bottom area of 28 cm.^{2} and a height of 40 mm. are used for starting stock cultures. The sides of these containers slope outward, giving a relatively large water-surface area. A 100 mm. petri-dish cover fits snugly over the top. These inexpensive dishes have the advantage of holding a sufficiently large volume of water; they are easy to examine under the microscope, and removal of attached foraminifera is facilitated because of the sloping side of the dish. Benthonic diatom food stocks are also grown in these containers, but 500 cc. Erlenmeyer flasks are more suitable for the green flagellates.

Some foraminifera cultured in our laboratory do not require living food, and with these forms the husbandry is relatively easy. Such species can be kept in "sterile" sea water, and suitable dead organic food added regularly from time to time. *Chlamydomonas* cells which have been killed by heating to 50° C. and then added to the culture form an "artificial detritus" on the bottom of the dish, upon which the foraminifera feed with apparent relish. At our laboratory the cultures are fed twice weekly. The amount of food varies with several factors and must be determined by experiment for each species and for each culture. Too much food will result in excessive bacterial activity, and too little food will not provide for optimum growth of the species.

If the foraminifera will eat only living material, this can be provided most easily by feeding them diatoms or flagellates, either grown in the same culture or regularly provided from another culture. Suitable algal food cultures may be easily maintained in the laboratory. Arnold (1954*b*) has given a recipe for Föyn's "Erdschreiber" similar to that used in our laboratory for the culture of these food stocks. It is necessary to have a varied supply of diatoms and flagellates, particularly for nutritional experimentation. These may be cultured from species found in the original sample along with the foraminifera, or they may be from standard laboratory culture stocks.

The writer maintains cultures of *Chlamydomonas, Platymonas, Amphidinium, Nitzchia,* and several species of *Navicula,* as well as several other unidentified forms, for food supply. Each stock culture should be subcultured at intervals so that degenerative changes will not occur. Infrequently used cultures can be kept refrigerated under dim light so that subculturing can be postponed for much longer intervals. Routine stocks of food materials may be kept at higher temperatures and under more intense illumination to obtain maximum production.

A proper balance is essential between amount of food and the size and type of foraminiferal population. Although this balance often is maintained in impure cultures because of the interreactions of other organisms, many "pure" cultures are difficult to balance. The diatoms may reproduce so rapidly that they inhibit growth or even kill the foraminifera. Practical control in experimental cultures is possible through changes in the light intensity and/or concentration of mineral nutrients.

The other environmental conditions should be kept near the normal values encountered by the cultured species in its natural habitat. Temperature must be kept between the upper and lower reproductive limits of the species concerned. In some forms this range is narrow, whereas in others it may be very wide. At temperatures outside the reproductive temperature limits, the foraminifera may remain alive and yet not reproduce.

An accurate census of the population can be made only by a total count of all culture individuals at a given time. This is not practicable for large populations, and a more rapid sampling technique was devised. It was observed that the foraminifera tend to become evenly distributed in the culture container even though they may have been irregularly grouped at first. The projected area of 13 mm.^{2} formed by a Whipple counting reticle 3.6 mm. on a side at 20× magnification was selected as a unit area for the sampling procedure. By scribing marks at various points on the dish, the reticle could be aligned so that the same areas could be counted at different times. The average population of a number of such areas gives a measure of the culture, expressed as numbers of individuals per unit area.

Three types of temperature control were used. The lowest temperature, 14.5° C., was regulated by a constant-temperature refrigerator, while the other two "room temperatures" varied according to their location in the laboratory. Cultures fed with living *Nitzchia* were placed on a shelf near the window, where a thermograph recorded an extreme range of 18.0° to 30.0° C., with a mean of 24.5° C. Forms fed on dead *Chlamydomonas*, on the other hand, were kept in a darkened cabinet, close to the floor and as far away as possible from large-scale temperature fluctuations. In this location the temperature ranged from 19.0° to 26.0° C., with a mean of 22.2° C.

Salinities higher than that of normal sea water were obtained by evaporating La Jolla sea water of 33.5‰ salinity to one-half its original volume and then diluting the product with distilled water until the desired salinities were obtained. Lower salinities were obtained by dilution with distilled water.

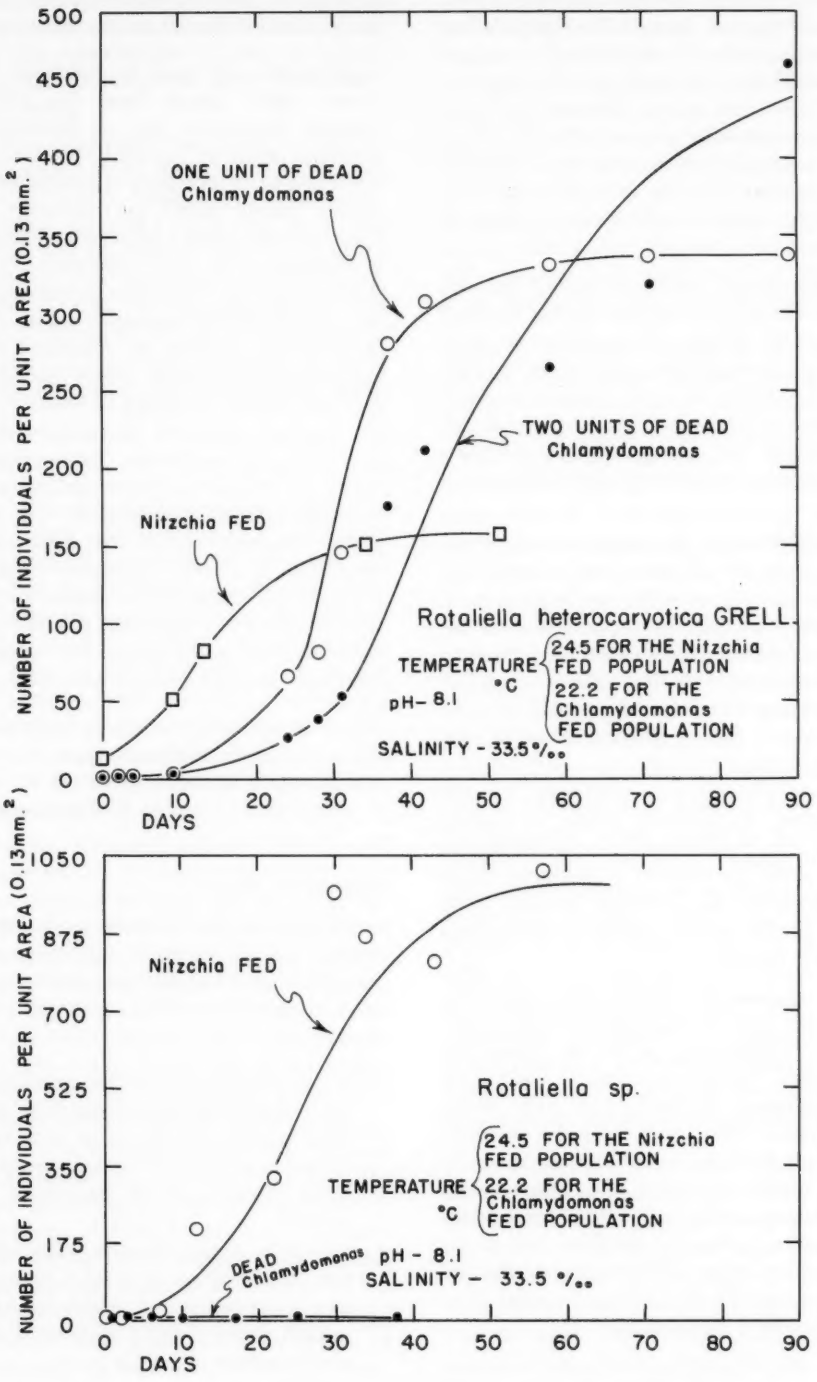
Experiments were made on *Rotaliella heterocaryotica*, a very small species from the intertidal zone at Rovigno, Yugoslavia, and on *Rotaliella* sp. from the intertidal zone at La Jolla, California. The normal development of *Rotaliella heterocaryotica* is now well known (Grell, 1954). Its life cycle consists of an alternation of sexual (gamont) and asexual (agamont) generations. In *R. heterocaryotica*, the two stages are morphologically indistinguishable and can be differentiated only by cytological methods. The gametes of the sexual gamonts are amoeboid, and their fusion occurs within the same parent test. Fusion results in the formation of from five to twelve young agamonts, the number produced presumably depending upon environmental conditions. After approximately two weeks' growth, the six-chambered agamont has reached its adult size of approximately 60μ and reproduces again. Reproduction of the agamont involves the formation of twelve agametes which develop into the gamonts of the sexual generation. Approximately two weeks later, the 60μ gamonts consist of five chambers, at which stage the gametes are again produced and the cycle is complete.

Rotaliella sp. is similar to *R. heterocaryotica* and is the same size, but differs from it in several characters. The life cycle is not known in detail but presumably is comparable to that of *R. heterocaryotica*.

EXPERIMENTAL RESULTS

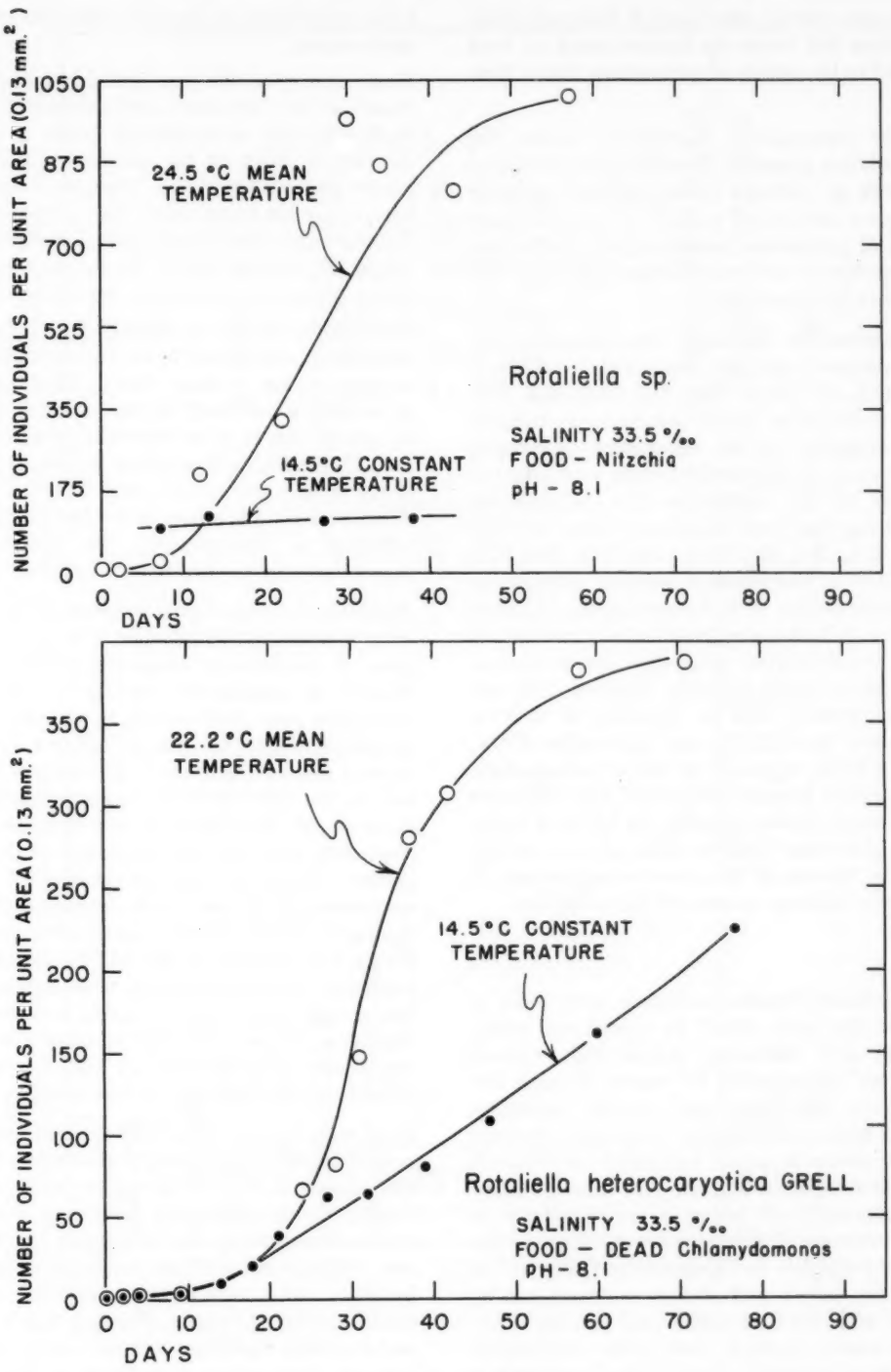
Food requirements: Text-figure 1 summarizes observations on cultures of *Rotaliella* sp. and *R. heterocaryotica* fed living *Nitzchia* and varying amounts of dead *Chlamydomonas*. Examination of text-figure 1 shows:

1. *Rotaliella heterocaryotica* apparently can utilize both dead *Chlamydomonas* cells and living *Nitzchia*, whereas *Rotaliella* sp. appears to be unable to feed upon dead *Chlamydomonas* and must have living *Nitzchia* or its equivalent for population growth.
2. *Rotaliella heterocaryotica* populations fed twice the concentration of dead *Chlamydomonas* grew at a lower initial rate, which later approached the growth curve of the population fed with one unit concentration of food.
3. *Rotaliella heterocaryotica* populations fed with one unit concentration of dead *Chlamydomonas* had a population maximum of approximately 320



TEXT-FIGURE 1

Growth of laboratory populations of *Rotaliella* sp. and *Rotaliella heterocaryotica* Grell when fed different food materials.



TEXT-FIGURE 2

Growth of laboratory populations of *Rotaliella* sp. and *Rotaliella heterocaryotica* Grell at two temperatures.

per unit area. On the other hand, *R. heterocaryotica* populations fed twice the concentration of food appeared to be capable of populations higher than this.

Temperature experiments: Text-figure 2 shows the rate of population growth of *Rotaliella heterocaryotica* and *Rotaliella* sp. cultured at two different temperatures. Cultures maintained at 14.5° C. showed much lower rates of population growth in both species than did those grown at room temperatures (22.2° C. and 24.5° C. mean temperatures).

Salinity experiments: Rotaliella heterocaryotica cultures were prepared using sea water of eleven different salinities, 16.8, 20.1, 23.5, 26.8, 30.2, 33.5, 40.2, 46.9, 53.6, 60.3, and 67.0‰. These cultures were then allowed to evaporate as the experiment progressed. On the fifty-second day, distilled water was added to replace that lost by evaporation (10 cc.) and the salinities at this time were calculated. These salinities were 21.0, 25.1, 29.4, 33.5, 37.5, 41.9, 50.2, 58.6, 67.0, 75.4, and 83.7‰. The effect of different salinities on the population growth in *R. heterocaryotica* is shown in text-figure 3. Laboratory populations increased at salinities as low as 26.8‰; moreover, the rate of population growth at initial salinities between 26.8 and 30.2‰ was greater than at salinities of 33.5‰. Salinities lower than 23.5‰ and higher than 37‰, on the other hand, appeared to inhibit reproduction, for the laboratory populations beyond these salinities did not increase. Curves showing the effect of initial salinities higher than 33.5‰ upon culture growth are not given because of the almost complete lack of growth of the cultures at these higher salinities.

DISCUSSION

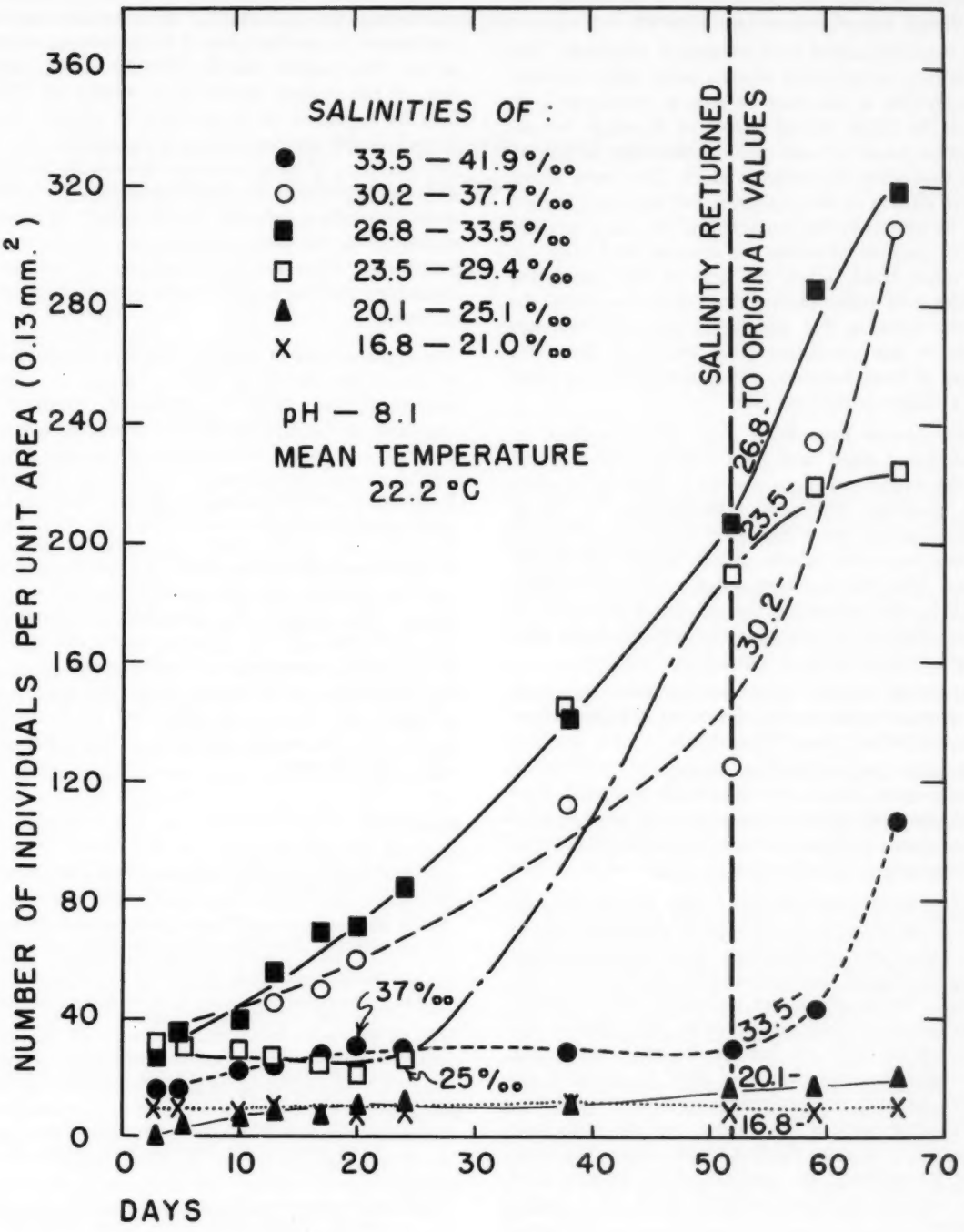
General statement: Marine conditions, even those of the smallest tide pool, cannot be reproduced within the confines of a laboratory culture dish. Certain "model effects" undoubtedly are caused by such factors as space restrictions and steadily increasing metabolites. More or less regular flushing and renewal of the water occurs in nature, but this is very difficult to acomplish in cultures. In a tide pool there are many diverse organisms, each having a particular part to play in the economy of that environment. Such a community may be said to be "dynamically balanced." In the laboratory only a part of such a system can be established, with the foraminifera and perhaps a few small protozoans, bacteria, and other unidentified forms. When a dynamic balance finally is achieved in such a culture, it will not be the same as that in the tide pool and probably will be found to contain different proportions of only a few elements of the natural environment.

Since a complex tide pool probably cannot be reproduced in the laboratory, the alternative may be to work with one environmental factor at a time, determine its effect on the population, and only later study combined factors. Complete duplication of nature may not be necessary for our purposes, since it may be only a few factors, such as temperature, food supply, or salinity, which set the limiting conditions for an animal in a particular environment.

The relative change or stability of population size in a species is considered to be a good indication of its response to any ecologic factor, reflecting the range of conditions required for the success or failure at all growth stages of an organism. In a young culture under favorable environmental conditions the number of individuals at successive time intervals will show a characteristic form known as the logistic growth curve (Allee *et al.*, 1949, p. 301). The growth form of a population may be divided into at least six regions.

These are: (1) the initial reaction of the population to its environment; (2) the period of increasing growth rate; (3) the period of decreasing growth rate; (4) the plateau or equilibrium position about which the population may fluctuate for an indefinite time; (5) period of decline because of adverse environmental factors; and (6) extinction: the death of the population. In the behavior of the cultures described above, these periods were found to vary in duration and size depending upon the species and the conditions in the culture. Thus, for any single species it will be environmental factors which determine the shape of the curve. Under adverse reproductive conditions, as shown, for example, by the 16.8‰ salinity curve in text-figure 3, there appears to be little, if any, population growth. With more favorable environmental conditions, as in the 26.8–30.2‰ salinity cultures, the population curve rises sharply and if continued presumably would reach the plateau position.

Food requirements: Foraminifera have been reported to feed upon a wide variety of particulate food. While this appears to be true for species such as *Rotaliella heterocaryotica*, it does not seem to be true for others such as *Rotaliella* sp. (see text-figure 1). Many forms may have specialized food requirements and may be found to ingest only certain materials, such as particular species of diatoms. The fact that a foraminifer under culture conditions will eat only a certain food, however, does not necessarily mean that this is its principal food under natural conditions. Some foods may be more efficiently captured and metabolized than



TEXT-FIGURE 3

Growth of laboratory populations of *Rotaliella heterocaryotica* Grell at different salinities.

others, and some may contain toxic elements. The nutritional role of bacteria is unknown.

The concentration of food material is important. Too much may be as bad as or even worse than too little. A suggestion of this may be seen in text-figure 1, in which the initial rate of growth of *Rotaliella heterocaryotica* when fed one unit concentration is greater than that when fed twice as much. The lower initial rate of growth in the population fed two units of food may be caused by the "antagonism" of a large population of bacteria attacking the uneaten food cells. On the other hand, when the size of the population enables it to utilize the available cells more fully, the growth curve in this population gradually becomes similar to the population given less food. The extra supply of food, however, allows the culture to maintain a higher population level.

Similar results have been observed in cultures in which living algae have been used as food material, but the amount of algae present is difficult to assess with accuracy. Excessive concentrations of living diatoms and/or green flagellates have been observed to have depressive effects on the foraminiferal populations. This has also been noted by Arnold (1954*b*, p. 411), who attributes the phenomenon partly to certain chemical effects associated with excessive algal growth, and partly to a form of algal choking.

Temperature results: There appear to be at least five critical temperatures of interest. These include (adapted from Orton, 1920, p. 360):

1. Lowest temperature for survival;
2. Lowest temperature for successful reproduction;
3. Optimum temperature for successful reproduction;
4. Maximum temperature for successful reproduction;
5. Maximum temperature for survival.

The two mean temperatures of 14.5° C. and 22.2° C. used in the experimental studies of *Rotaliella heterocaryotica* appear to lie within the reproductive temperature-range of this species. This was shown experimentally by the population growth at each indicated temperature. Further experiments may define the reproductive limits of this species more accurately. The maximum temperature of 26.0° C., endured for limited periods, was apparently within the survival temperature-range of the species, and may also have been within the reproductive range. Since this maximum temperature was maintained for only a short time, nothing is known of the effect of a longer exposure.

Salinity results: The lack of growth at salinities of 16.8–20.1‰ is not surprising in view of what is known of the ecology of other foraminifera. Such a lowered salinity may be one of the major factors in preventing the colonization of brackish-water environments by species adapted to open-ocean environments. The sudden growth, after the twenty-fourth day, of the culture started at a salinity of 23.5‰ may be explained by an increase in salinity due to evaporation from the culture dish. During the first fifty-two days of the experiment, the salinity increased from 23.5‰ to 29.4‰. Interpolation between these two values indicates that a salinity of approximately 25‰ was presumably reached on the twenty-fourth day. After this time, presumably because of favorable salinities, a rapid increase in the population occurred.

The apparent lack of growth, after the twentieth day, of the culture started at 33.5‰ salinity can be explained similarly. Here the population, which at the beginning of the experiment was increasing normally, gradually decreased its productivity as the salinity rose above the critical value. The critical salinity, as determined by interpolation, appears to have been approximately 37‰.

It is curious to find such results in a species originally from the Adriatic Sea, where relatively high salinities obtain. This suggests that *Rotaliella heterocaryotica* may have been living near its upper salinity limit for successful reproduction. Another possibility is that the immediate environment where the species was collected may have been influenced by fresh-water runoff, and the species therefore rarely experienced such high salinities.

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ABSTRACT: *Examination of the literature and specimens of various species has shown that the diagnosis of* Gaudryina *must be emended and a new synonymy proposed. Both these requisites are embodied in the present paper.*

Observations on the foraminiferal genus Gaudryina d'Orbigny, 1839

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INTRODUCTION

The foraminiferal genus *Gaudryina* was founded by d'Orbigny in 1839, the first-named species being *Gaudryina rugosa* d'Orbigny, 1840, which was obtained from the Chalk of Meudon and Saint-Germain and in the area of l'Yonne at Sens. No type locality was indicated, and the designation of this species as the type was made by Cushman in 1911. The generic description noted a free test initially subtriangular in section and later compressed. A youthful trochoid stage, in which the chambers are spirally coiled, is followed by an adult arrangement of them in two alternating series "comme chez les Énallostègues textularidées." The aperture is a transverse slit on the inner margin of the last-formed chamber. D'Orbigny referred to the wall as wrinkled, but did not mention its arenaceous character. That he appreciated it is evident, however, from his comparison of the genus with the triangular (triserial) valvulines early in its ontogeny and with the biserial textulariids when ephebic.

Brady (1884) made a similar observation in stating that it comprises a group of forms which are "verneuiline at the commencement and subsequently textularian in their mode of growth," and included it in the subfamily Textularinae of his family Textularidae In his synonymy of *Gaudryina*, he listed *Sagrina* (pars) d'Orbigny, 1840; *Heterostomella* Reuss, 1865, and *Plectina* Marsson, 1878. Some of these were reinstated by later taxonomists, and the classification of *Gaudryina* has been altered by Glaessner (1945) and Cushman (1948), both of whom placed it in the family Verneuilinidae. It must be noted, however, that the definition of this family given by the former is very wide, as it includes not only Cushman's Verneuilinidae but also his Valvulinidae. Justification exists for this procedure, as will become evident from facts adduced later in the present paper.

Glaessner defined *Gaudryina* as "triserial in the earlier stage, in which the test is often triangular in transverse section, later biserial with distinct sutures; wall coarsely or finely arenaceous; aperture typically a slit along the suture at the inner margin of the last-formed chamber or extending from the suture into the apertural face. Upper Jurassic to Recent." Cushman's description is similar, but, with reference to the apertural characters, he stated that "in the early stages," it lies "at the inner margin of the last-formed chamber, usually with a distinct re-entrant, in some species tending to become terminal in the final chamber."

Three subgenera have been founded by Cushman, namely *Gaudryina* sensu stricto, *Siphogaudryina* and *Pseudogaudryina*. The first, which has the same type species as the genus itself, is distinguished by having the inflated chambers of the same general shape in both the triserial and biserial portions of the test. The second, founded in 1935 with the type species *Gaudryina (Siphogaudryina) stephensoni* Cushman, has the biserial part of the test square in section with projecting fistulose ribs at the angles. It may be that the latter become broken on the exterior, and in this event a row of openings occurs in their place. Lastly, *Pseudogaudryina* Cushman, 1936, has the type species *Gaudryina (Pseudogaudryina) atlantica* (Bailey), and is characterized by having the test triangular in section in the adult part. This results in the chambers of one series being truncate, with the opposite series angular.

A number of genera exists which are related to *Gaudryina*, and among these may be mentioned *Migros* Finlay, 1939, a Tertiary genus differing only in having the aperture rounded in the apertural face but connected with the inner margin by a narrow opening; *Bermudezina* Cushman, 1937, Upper Cretaceous to Miocene in range, again differing only in apertural characters, the aperture consisting of a rounded tubular neck in a terminal position on the end chamber; *Heterostomella* Reuss, 1865, an Upper Cretaceous genus having a youthful aperture like *Gaudryina* but later with a terminal aperture and "frequently . . . a slight neck" (Cushman, 1948); *Marssonella* Cushman, 1933, a genus ranging from Cretaceous to Eocene and differing in having four or five chambers to the whorl at the initial end; *Dorothia* Plummer, 1931, which again is distinguished by having "more than three chambers in the first whorl," according to its founder, and ranges from Cretaceous to Recent; *Plectina* Marsson, 1878, which has as many as five chambers to the whorl in the early stages and has the aperture initially textularian and later rounded in the terminal face, but without a neck; it ranges from Cretaceous to Recent; and finally *Karreriella* Cushman, 1933, a Tertiary genus with five or more chambers to the whorl in youth and an aperture just above the base of the inner chamber margin, with a distinct neck.

While both *Siphogaudryina* and *Pseudogaudryina* range from Upper Cretaceous to Recent, the range of *Gaudryina* sensu stricto is given as Upper Jurassic to Recent by Glaessner (1945). Cushman (1948) referred to "specimens of *Gaudryina* from the Triassic" in his introductory notes to the Verneuilinidae, thereby contradicting the range of Jurassic to Recent which he gave under the generic heading. One species has been recorded from the Upper Triassic by Tappan (1951), namely *Gaudryina (Gaudryina) adoxa*, a very small form. A few specimens were obtained from cores from borings in the Shublik formation west of Cape Simpson, northern Alaska. *Gaudryina* does not appear to occur in rocks of pre-Upper Triassic age, and the author therefore doubts the suggested affinity between it and *Digitina* Crespin and Parr, 1941, a Permian genus, although Cushman referred to it as "close." The Cretaceous genera *Gaudryinella* Plummer, 1931, and *Pseudogaudryinella* Cushman, 1936, are probably derivatives of *Gaudryina* in which the biserial condition of the adult part of the test in the latter becomes superceded by an uniserial arrangement of the chambers. *Rudigaudryina* Cushman and McCulloch, 1939, has the adult chambers in an irregular spreading series and appears to bear a similar relationship to *Gaudryina* as the anomalinid genus *Cibicidella* Cushman, 1927, does to *Cibicides* Montfort, 1808.

DIAGNOSTIC CHARACTERS

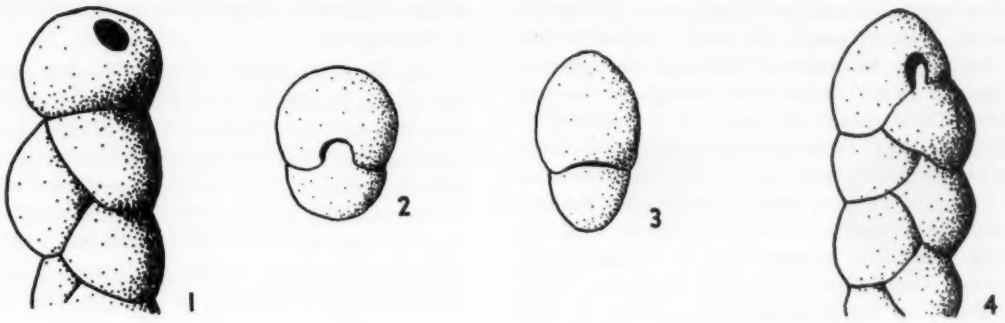
If *Siphogaudryina* and *Pseudogaudryina* are considered to be specialized variations of *Gaudryina*, and the latter subgenus alone is contrasted with the numerous genera which show affinities and have already been mentioned, it is evident that the taxonomic distinctions between *Gaudryina* and the other genera are based upon two primary features, namely the apertural characters and the arrangement of chambers. If we exclude the derivative forms and accept the position of *Digitina* as uncertain, this statement can be expressed more precisely as follows: The taxonomic distinctions between *Gaudryina* and its related genera are based upon the apertural characters and the arrangement of chambers in the initial stages of growth. Some of the relevant genera, such as *Bermudezina*, are distinguished by the former criterion, others, such as *Dorothia*, by the latter, and still others, such as *Karreriella*, by a combination of both.

SPECIMENS EXAMINED

Forty-seven specimens of *Gaudryina (Gaudryina)* cf. *flintii* Cushman, 1911, from Recent seas off the Shetland Islands were examined and showed great variation in apertural characters. One specimen of *Gaudryina parallela* (Reuss) var. *chapmani* Franke, 1928, from the upper Chalk (zone of *Belemnitella mucronata*) of Norwich, showed a short terminal uniserial development of chambers and a subterminal rounded aperture (text-fig. 1). Two specimens of *Gaudryina (Siphogaudryina) howelli* McLean, 1952, from Recent seas off Cape Byron, New South Wales, were inspected. In addition, four specimens of *Marssonella trochus* (d'Orbigny) from the Upper Cretaceous of Mexico, and one specimen from the *Ostrea lunata* zone of the Chalk at Trimingham, Norfolk, were examined.

Comparative studies were carried out on several species of *Dorothia*, including *Dorothia conula* (Reuss) and *Dorothia pontoni* Cushman, 1933, the former from the *Belemnitella mucronata* zone of the Chalk of Norfolk and the latter from the Upper Cretaceous of Mexico. Two specimens of *Plectina ruthenica* (Reuss) from the *Schloenbachia varians* zone of the Chalk were examined from Portsdown well no. 1 (800 feet).

The author is indebted to the trustees of the British Museum (Natural History) for making available some of the material studied in the present paper.



TEXT-FIGURE 1

Gaudryina (Gaudryina) parallela (Reuss) var. *chapmani* Franke. Specimen showing the tendency to uniserial growth found in some gaudryine species. The apertural characters are interesting, since the round aperture is situated in a slight terminal depression and is not in contact with the suture separating the penultimate and end chambers.

TEXT-FIGURE 2

Gaudryina (Gaudryina) cf. *flintii* Cushman. Specimen viewed aperturally to show the low arched aperture placed at the base of the apertural face of the last-formed chamber.

TEXT-FIGURE 3

Gaudryina (Gaudryina) arguta Bandy. Here the aperture is textularian in form, consisting of a low, wide slit located at the inner margin of the end chamber.

TEXT-FIGURE 4

Gaudryina (Gaudryina) longa Bermudez. Specimen showing the very highly arched aperture at the base of the end chamber. Morphologically, this appears to be intermediate between the conditions shown in text-figures 1 and 3. Note also the different degrees of embrace between the chambers in the biserial parts of the test in text-figures 1 and 4.

INTRA- AND INTERSPECIFIC VARIATION

Examination of both the literature and specimens of various species showed that great intra- and interspecific variation occurs within the genus sensu stricto. The number of chambers in the biserial part of the test varies from three pairs in *Gaudryina (Gaudryina) healyi* Finlay, 1939, to eight or ten pairs in *Gaudryina (Gaudryina) pseudocollinsi* Cushman and Stainforth, 1945, although the specific value of this information is diminished in view of the fact that almost as wide a range is found in *Gaudryina (Gaudryina)* cf. *flintii* and also in other recorded species. The shape of the chambers in this portion of the test shows much variation, from "inflated or projecting" in *Gaudryina (Gaudryina) eocaenica* van Bellen, 1941, "much inflated" in *Gaudryina (Gaudryina) karihaensis* Asano, 1950, "not inflated" in *Gaudryina (Gaudryina) gracilis* Cushman and Laiming, 1931, and "somewhat polyhedral in shape in the later portion" in *Gaudryina (Gaudryina) disjuncta* Cushman and Jarvis, 1929, to "slightly inflated, rapidly increasing in width as added" in *Gaudryina (Gaudryina) vadaszi* Cushman and Glazewski, 1949.

Variation in apertural shape is very marked both intraspecifically and between species. This is illustrated by text-figures 1-4. Here, every variation is seen from the "elongate low arched opening at the base of the last septal face" of *Gaudryina (Gaudryina) arguta* Bandy, 1951 (text-fig. 3) through the subcircular opening of *Gaudryina (Gaudryina)* cf. *flintii* Cushman, 1911 (text-fig. 2, specimen number 31), and the highly arched aperture "at the inner margin of the last chamber" of *Gaudryina (Gaudryina) longa* Bermudez, 1949 (text-fig. 4), to the condition in the figured specimen of *Gaudryina (Gaudryina) parallela* (Reuss) var. *chapmani* Franke, 1928 (text-fig. 1), in which the aperture is rounded, and located in a depression and not in contact with either the penultimate chamber or the suture.

In the case of the varietal form, the last chamber is uniserial, and several other species also show what can be regarded only as a trend toward the assumption of uniserial growth. Among these are the Eocene species *Gaudryina (Gaudryina) bundensis* van Bellen, 1946, in which "the last chamber tends to become ter-

minal" and the aperture also is terminal, and the Oligocene species *Gaudryina (Gaudryina) fortiuscula* Bermudez, 1949, in which the adult portion is "biserial, tending to be uniserial," although the aperture is "large and round, at the inner margin of the last chamber." These cannot be regarded as ancestral to *Gaudryinella* and *Pseudogaudryinella,* since these genera had already attained uniseriality in Cretaceous times. It is interesting to note, however, that the former possesses a rounded, terminal aperture. That the tendency persists in present seas is evidenced by *Gaudryina (Gaudryina) subtenuis* Cushman, 1938, which shows it. Interspecific size variation is very pronounced, the length ranging from 0.13 mm. in small specimens of *Gaudryina (Gaudryina) adoxa* Tappan, 1951, to 4 mm. in *Gaudryina (Gaudryina) robusta* Cushman, 1913.

A difficulty encountered in dealing with literature is the ambiguous phrasing of some diagnoses and what can only be referred to as the frivolity of others. An example of the former is *Gaudryina (Gaudryina) arguta* Bandy, 1951, the type description of which refers to the fact that the chambers are "rather indistinct in the early part, about three sets of triserially arranged chambers in the early part" — a rather confused statement. The latter can be well illustrated by *Gaudryina (Gaudryina) rudis* Wright, 1900. In the type description may be found the extraordinary statement that "this species, in consequence of its rough exterior, does not show the chambers distinctly, and for the same reason its dimorphous mode of growth is not very apparent. It is generally found with the apex of the test broken off, and when such is the case three chambers are exposed in cross-section; the later chambers are arranged as in *Textularia.*" It is obvious that if the facts are as indicated, there can be no certainty that the species is assigned to the correct genus. In expressing its taxonomic position, the form *Gaudryina (Gaudryina)? rudis* Wright, 1900, is the most that may be stated.

THE CASE OF DOROTHIA

The genus *Dorothia* was erected by Plummer in 1931, and *Gaudryina bulletta* Carsey, 1926, was designated as the type species. The type description stated that "the essential feature that distinguishes this new genus *Dorothia* from *Gaudryina* is the youthful trochoid spire composed of more than three chambers in the first whorl. By a gradual lengthening of the successive chambers and a consequent decrease in the number of chambers per whorl, the adult stage of compact biserial chambers is reached and maintained. The genotype, *Dorothia bulletta* (Carsey), exhibits the diagnostic generic character more strikingly than any of its congeners."

In the type description, Carsey (1926) stated that the "initial chambers (are) triserial, remaining chambers biserial," but Plummer contradicted this by remarking that "in both the megalospheric and microspheric forms the first whorl is composed of five or six very slowly enlarging short chambers." Carsey's original description is inadequate for comparative purposes, since she neither designated a type level nor named the depository of the type specimen.

A study of the literature shows that some species of *Dorothia* have been named without sufficient care. A case in point is *Dorothia agrestis* Finlay, 1939, the type description of which stated: "Coarsely irregular grains with little cement; surface very rough. Triserial chambers obscure, about a third of length, then about four biserial. Sutures merely indicated; terminal face at angle of about 45°, with large rounded aperture at base. Size, 1.2 mm." It is obvious that if the triserial part is obscure, the initial whorl cannot have been examined. If it was, no comment is made as to how many chambers it comprises. There is, in short, no justification for definitely assigning this species to the genus *Dorothia.*

In his type description of the species *Dorothia yaguatensis,* Bermudez (1949) observed that "those (chambers) of the early portion (are) quite indistinct." He made substantially the same reference to the juvenile stages of his *Dorothia debilis* erected in the same year. Parr (1950) is less equivocal in the type description of his *Dorothia tortilis.* He states that the "arrangement of (the) earliest chambers (is) uncertain, then triserial." There can be no doubt that these and other species have not been thoroughly examined, or if they have, proved so intractable as to preclude their assignment to this genus, defined as it is by the number of chambers in the initial whorl.

Consideration of other species of the genus shows that the phraseology of Plummer's original diagnosis was illogical. For example, *Dorothia alabamensis* Cushman, 1940, has the "earliest whorl with four or five chambers," *Dorothia arenata* Cushman, 1936, has the "early whorls with five chambers," *Dorothia glabrella* Cushman, 1933, has the "earliest portion with four or more chambers in a whorl" — the author being quoted in each case. From these and other examples, it is evident that forms with four chambers in the initial whorl are not separated from those with five, nor are those with "more than four" separated from those with four.

Herein lies the inherent illogicality of the definition of the genus; if forms with three chambers in the initial whorl are to be diagnosed as species of *Gaudryina* and forms with "more than three" as *Dorothia,* and if this is to be (as stated by Plummer) the only difference between the two genera, why not separate forms with four chambers in the initial whorl from those with five and so on? In fact, the present author suggests that this would be logical procedure if greater "splitting" is desired.

It is his opinion, however, that "splitting" has already gone too far, and that it is quite unjustifiable for *Gaudryina* and *Dorothia* to be differentiated. The number of chambers which surround the proloculum depends on their relative sizes and rates of expansion. In several species, it has been observed that expansion rates in the biserial part of the test may be irregular, and in any event, a very small alteration in the rate of chamber expansion at the initial end would suffice to convert a quadriserial form into a triserial one. And what category would satisfactorily include intermediate stages? It is an unavoidable conclusion that the genus *Dorothia* must be regarded as invalid and synonymous with *Gaudryina.*

SOME RESULTANT CONCLUSIONS

It is inferred from the case of *Dorothia* that the number of chambers per whorl in the initial stages of growth cannot be accepted as a valid criterion for generic differentiation. Hence, not only *Dorothia* but also any other genera based upon this character must be regarded as synonymous with the earlier-named *Gaudryina.* This means that *Marssonella* Cushman, 1933, must be demoted to the level of a synonym. There is also a strong case for the invalidation of *Plectina* Marsson, 1878, and *Karreriella* Cushman, 1933.

The intra- and interspecific variation in apertural characters in *Gaudryina* has already been noted, and the only possible inference is that they are of no value in establishing *generic* as distinct from *specific* differences. Hence, *Migros* Finlay, 1939, *Bermudezina* Cushman, 1937, and *Heterostomella* Reuss, 1865, must be regarded as synonymous with *Gaudryina.* In addition, the invalidity of *Plectina* and *Karreriella* would appear to be confirmed.

It is evident that a comprehensive synonymy and an emended diagnosis for the genus *Gaudryina* are necessary, and it remains for these to be stated.

TEXT-FIGURES 5-6

5, relationship of chambers in the initial whorl of a megalospheric gaudryine; 6, relationship of the chambers in the initial whorl of *"Dorothia" conula* (Reuss).

EMENDATION OF THE GENUS GAUDRYINA

Gaudryina d'Orbigny, 1839
Text-figures 5-6

Heterostomella Reuss, 1865.
Plectina Marsson, 1878.
Dorothia Plummer, 1931.
Marssonella Cushman, 1933.
Karreriella Cushman, 1933.
Bermudezina Cushman, 1937.
Migros Finlay, 1939.

Diagnosis: Test with an initial whorl of three or more chambers, trochospiral in youth with rapid attainment of triserial growth and triangular cross section. The later development is characterised by biserial arrangement of the chambers with more distinct sutures, which are typically depressed, and oval or circular cross section.

In some species there is a tendency toward ultimate uniserial growth. In the subgenus *Gaudryina,* the chambers are usually slightly inflated and similar in shape in both the juvenile and adult stages of growth. In the subgenus *Siphogaudryina,* the early stages are triserial, and the biserial part of the test is square in section with projecting fistulose ribs at the angles. In the subgenus *Pseudogaudryina,* the initially triserial test retains its triangular cross section when adult, with the result that the chambers of one series are truncate and those of the opposite series are angular.

Although arenaceous throughout, the wall may be coarsely so or composed of fine fragments and much cement. In consequence, the surface may range from very rough to smooth.

The aperture is extremely variable in both shape and position. It may lie at the inner margin of the last-formed chamber and take the form of a textularian slit, or may be distinctly arched. It may have a well-marked lip or a slight neck. It may not be in contact with the suture separating the penultimate and ultimate chambers at all, and may be round in a slight depression, or show any of the structural variations noted above. It may lie in the apertural face and be connected with the inner margin by a narrow opening.

Remarks: Cushman (1948) placed the genus *Gaudryina* in his family Verneuilinidae, but *Marssonella, Plectina, Dorothia* and *Karreriella* were put into the Valvulinidae. Even if these forms were significantly distinguished, there is no justification for this separation into a different family. Indeed, there are strong grounds for doubting the validity of Cushman's assertion that in valvulinids the "test in the earliest stages of the more primitive forms (is) triserial, later with a secondary spiral development increasing the number of chambers to four, five or more in a whorl," since Hofker (1949) pointed out that "in no known species of this group does the number of chambers increase in later whorls, but always decreases."

The author does not believe that the grouping of genera into these two families as defined by Cushman is justified. Future investigations into relevant genera will be undertaken, and it is hoped that a more logical, "natural" classification will result, with less unnecessary "splitting."

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ABSTRACT: *A simple, inexpensive die and its use in producing plastic depression slides for storing foraminifera, pollen or other microfossils are described.*

The construction and use of a simple die for plastic micropaleontological slides

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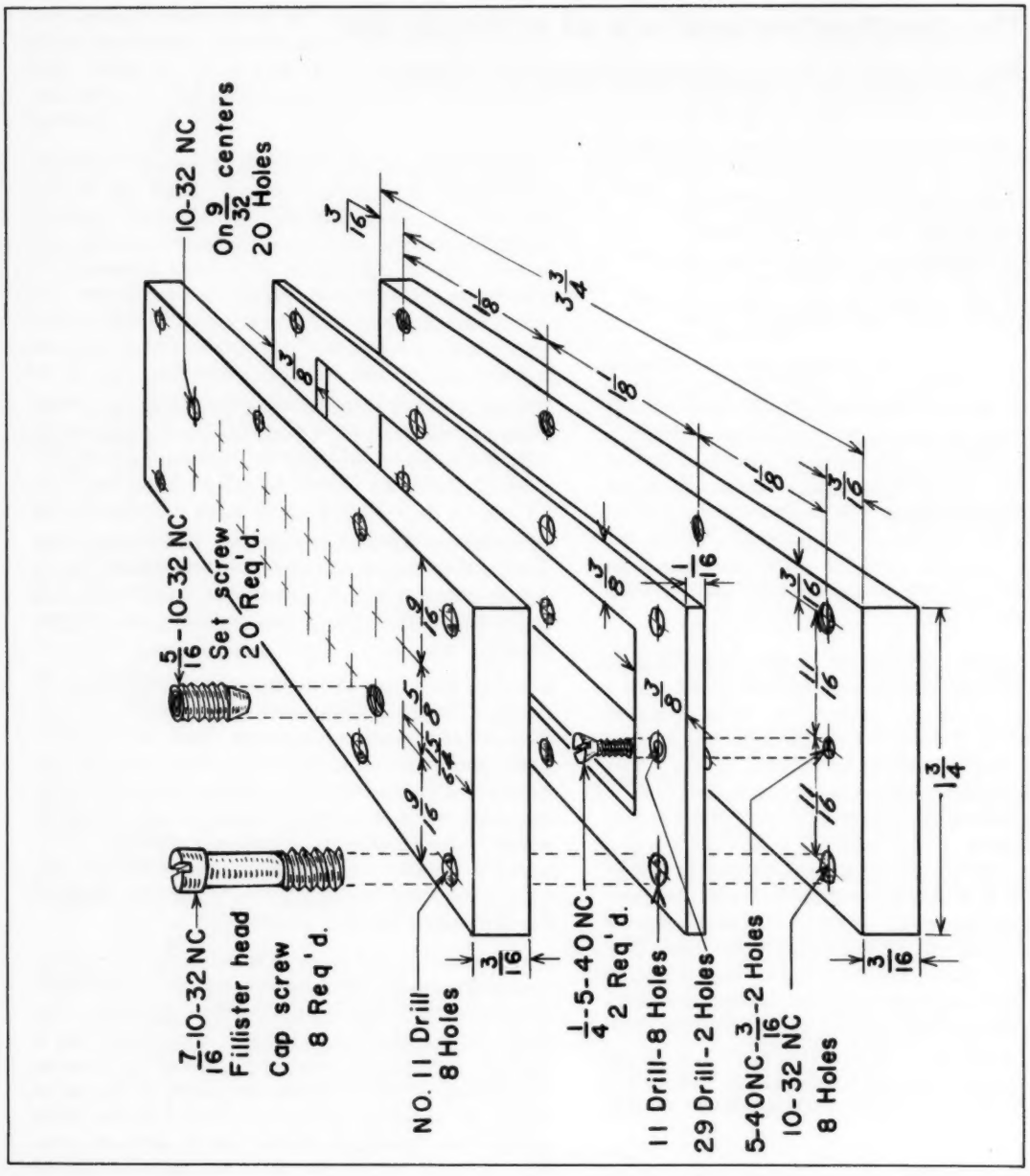
A single- or multiple-depression plastic slide suitable for storing micropaleontological specimens in either a dry or wet condition may be constructed in two or three minutes through the use of a homemade die of the type described below. The depressions are formed by inserting one- by three-inch blanks into the die and heating the assembly until the plastic becomes sufficiently soft to permit the operator to close the die upon it.

The plastic blanks may be cut to size (from clear or opaque heat-labile plastic, such as "Plexiglas") with a fine-toothed handsaw, bandsaw or abrasive cutoff wheel fitted to a circular saw. Clear plastic may be used, with the attendant advantages of the transparent cell or slide enumerated by Scheffen (1937), but a dark-colored opaque plastic is suitable for routine examination under reflected light. The popular glass-topped sheath of the type described by Chapman (1902) and Plummer (1929) provides adequate protection for specimens contained within the depression slide. If clear plastic is employed, the paper base of the sheath should be black rather than white, to afford a suitable background against which the specimens may be examined without unsheathing the slide. Permanent numbers or other markings may be added with special inks, or, if the slides are first lightly frosted with fine sandpaper, with pencil or ordinary ink.

The die, which requires no press for successful operation, consists essentially of two brass or copper plates between which the plastic blanks may be inserted, and a number of forming plugs that are to be pressed into the softened plastic to form the depressions. The illustrated die (text-fig. 1) was used in forming slides with twenty slightly tapered but flat-bottomed depressions measuring 4.0 mm. in diameter (at the top) and 1.5 mm. in depth, but a die of these dimensions will easily accommodate a middle row of forming-plugs. The number and variety of depressions producible by this technique are, of course, limited only by the skill and imagination of the person designing and making the die.

Headless set-screws are employed as forming-plugs in the die. The tip of each screw was turned down to a diameter of 3.5 mm., an operation which is most effectively performed on a lathe but which could be accomplished satisfactorily by grinding, filing or sanding the screw while it is being rotated by any device in which it can be chucked (such as a drill press or a portable electric drill). The screws are driven into tapped holes and can be adjusted to alter the depth of the depressions they are to form.

A simple rectangular guide or frame of the same thickness as the plastic blanks is fastened, by countersunk screws, to the inner surface of the base plate. The plate bearing the forming-plugs (set-screws) has a series of eight marginal holes that permit free passage to the body of the die-tightening screws by means of which the necessary pressure is exerted on the labile plastic. The interposed frame, which serves to position the blank within the die, is similarly penetrated by clearance holes, while the base plate contains the tapped holes into which the tightening screws are ultimately driven.



TEXT-FIGURE 1

Die for forming plastic depression slides under heat and pressure. All dimensions are in inches or fractions thereof.

A simple procedure for adjusting the forming-plugs so as to obtain the desired depression depth is as follows: Insert into the guide a one- by three-inch strip of metal or cardboard whose thickness corresponds to the difference between the desired depth and the actual thickness of the plastic blank; close the die tightly by means of the eight marginal screws; and then tighten the forming-plugs against the strip. The tightening screws may now be withdrawn, leaving the forming-plugs properly adjusted for subsequent use.

In use, a plastic blank is inserted within the guide frame of the base plate, and the tightening screws are driven until the two plates clamp the blank rigidly. The assembly is then placed over a source of heat, which can be a bunsen burner or other open flame if quick results are desired, or, if the operation can be performed more leisurely, an oven. Care should be exercised to avoid overheating, since melted plastic will flow into the most minute scratches on the die faces and upon cooling bear the imprint of these imperfections. If an open flame is employed, the die should be inverted so that the top plate, its forming-plugs, and the upper surface of the plastic blank receive the most heat; unless this precaution is taken, it is very difficult to prevent some melting (and consequent scarring) along the under surface of the slide. By using a slightly thicker guide frame in the die it is possible to insert a one- by three-inch strip of asbestos paper under the plastic blank, thereby preventing melting during the heating process. "Plexiglas" is usually adequately softened after forty-five to sixty seconds over a lively flame, and then the tightening screws — not the forming screws — are completely driven in so that the two plates exert a uniform pressure and permit no distortion. When complete contact is made between the top plate and the guide frame, the forming-plugs will have penetrated the plastic to the desired depth, and the die is ready to be cooled by dousing in water. The marginal screws are removed and the finished plastic slide is ready for the addition of sheath, specimens and labels.

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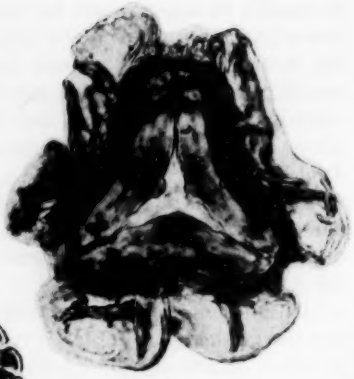
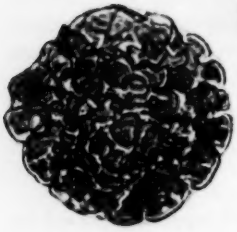
1a



1c



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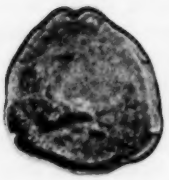


2a

2b

2c

2d

3a

3b

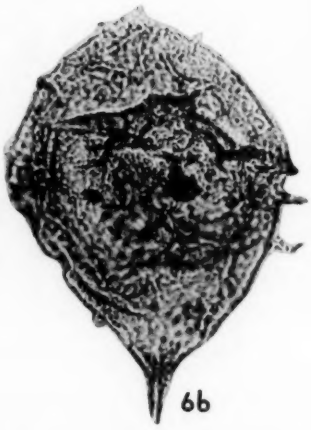
4a

4b

5a

5b

6a



6b

(for explanation please turn to page 375)

ABSTRACT: *Interest in the use of spores and pollen as a stratigraphic tool in the oil industry has recently been accelerated. It has already been demonstrated in a number of areas that these fossils occur in adequate numbers for general stratigraphic work. They are wind-blown, hence independent of ecologic conditions which restrict the distribution of marine organisms. They are therefore useful in solving certain stratigraphic problems under conditions in which foraminifera or other fossils are unsatisfactory.*

Spores and pollen – A new stratigraphic tool for the oil industry

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INTRODUCTION

Plant microfossils represent one of the most promising paleontological tools that has been offered to the oil industry in recent years. These interesting fossils have been used in the solution of a number of problems, particularly in connection with investigations of coal basins and in interpretations of Quaternary geology. Only in the last decade or so, however, have they been tested in general stratigraphic work. The success already achieved indicates that these fossils will prove to be a useful supplement to the foraminifera and other fossils presently used by economic paleontologists.

The author wishes to acknowledge the assistance of Dr. W. S. Hoffmeister of the Carter Research Laboratory in preparing the illustrations. The author is also indebted to the Humble Oil & Refining Company for permission to publish this paper. The paper was presented at the S.E.P.M. symposium on spores, pollen, and other microfossils useful in oil exploration, held in New York on March 30, 1955.

DEVELOPMENT OF SPORE AND POLLEN ANALYSIS

Dr. Erdtman (1943) has compared the development of the study of spores and pollen to the growth of a great river system. The science began as a mere trickle little more than one hundred years ago, with the curious observations of the first persons to notice these forms. Among the first, in 1833, was Henry Witham (Kosanke, 1950), who noted spores in thin sections of Lancaster coal. A few years later, in 1840, Morris illustrated the first fossil megaspores (Bennie and Kidston, 1886). From this small beginning, like an enlarging and branching river, spore and pollen analysis has constantly expanded into an increasing number of fields. Erdtman recently pointed out that in the last few decades more than 6000 papers in over 500 journals have dealt with spores and pollen in connection with taxonomy, morphology, genetics, plant geography, aerobiology, archeology, coal geology, Quaternary history and many other fields. This great stream of interest is now being joined by the field of general stratigraphy. In 1954, beginning with the April issue, The Micropaleontologist incorporated the Spore and Pollen Circular, formerly issued by Dr. Paul Sears of Yale University and Dr. L. R. Wilson of the University of Massachusetts. Recently it was announced that a new Swedish botanical journal, Grana Palynologica, under the editorship of Dr. Erdtman, will devote a section to the use of spores and pollen as guide fossils in pre-Quaternary geology. This publication, and the papers published in Micropaleontology, should serve to stimulate interest and further accelerate the stratigraphic application of these fossils. Some gauge of current interest in this field was furnished by a survey of North American workers taken last summer (Sears and Wilson, 1954). Sixty-one persons were listed, from twenty-two states and Alaska. Although oil companies were represented by less than 4 per cent of the total, it is significant that 56 per cent of those listed

were members of college geological departments and government geological surveys, or were affiliated with geological work in some manner.

The history of spore and pollen study, as previously noted, goes back little more than one hundred years. The earliest observations were made from thin sections, but in 1855 Franz Schulze discovered that coal could be macerated by chemical means without destroying the plant microfossils contained in it. Although this procedure provided a more flexible method of analysis, little attention was paid to these fossils until Reinsch in 1884, followed by Bennie and Kidston in 1886, began his systematic studies of isolated fossil spores. Of the many distinguished pioneers, only a few will be mentioned here. Among these are the Swiss geologist J. Fruh, who in 1885 enumerated most of the common tree pollens; F. Trybom, a Swedish zoologist, who in 1888 observed the resistant character of pine and spruce pollens in his studies of lake sediments, and suggested that these fossils should be useful to paleontologists; the German botanist and stratigrapher C. A. Weber, who in 1896 investigated the significance of pollen frequency ratios; and G. Lagerheim, a Swedish botanist, whose work on plant migrations, beginning about 1900, laid the foundation for paleobotanical interpretations of Quaternary geology. Lennart von Post, a student of Lagerheim, translated the ideas of his professor into a practical pollen system. He is credited with being the first to use pollen diagrams to illustrate differences between various stratigraphic horizons, and because of this work has been named by Erdtman as the father of modern pollen analysis. Arnold (1950) credits the work of Barlett (1928) as the real starting point of modern systematic studies. Bartlett revived and added to the neglected work of Reinsch, and thereby established the foundations of the present system of spore nomenclature. L. R. Wilson (1946) has credited the work of Raistrick and Simpson (1933) as the starting point of modern maceration methods, which have permitted paleobotanists more freedom in their analyses of various materials.

Until recently, spore and pollen research has been directed principally toward the study of coal beds, the interpretation of Quaternary geology, studies of plant history and migration, and related fields. None of these endeavors, except studies of coal seams that are useful in correlating strata in certain basins, has been of particular interest to the oil industry. A decade ago, only one oil company in the United States, so far as known, was conducting research on the use of spores and pollen as a general stratigraphic tool. Even today, less than half a dozen companies are reported to be engaged in such work. One of the principal objectives of the 1955 S.E.P.M. symposium on microfossils was to stimulate more research of this type. Only through the cumulative efforts of many persons can industry as a whole receive maximum benefits from this new tool. Preliminary investigations have already revealed the presence of usable spores and pollen in a variety of sediments, ranging in age from Devonian to Recent, over a large part of the southeastern United States. Encouraging results have also been reported from the western United States and from Canada, South America and elsewhere. Regional reconnaissance has indicated that these fossils are sufficiently common to permit the use of cutting samples in analyses, and, in several areas where they have been critically examined, the vertical ranges have been found to be sufficiently limited for both regional and local correlations.

With regard to their use in general stratigraphy, plant fossils are today approximately where the foraminifera were thirty-five years ago. It is to be hoped that their use in the oil industry will have as great an impact upon the development of the study of spores and pollen as the practical use of foraminifera had in that field of study. Hans Thalmann (1952) has emphasized this effect by pointing out that, during a twenty-year period prior to 1952, the energy expended in the study of foraminifera, as measured by the number of articles written, was as great as it had been in the entire preceding 100 years. If this progress is matched by an equal effort in the study of spores and pollen, the role of plant fossils as a stratigraphic tool will be assured.

SIZE, ABUNDANCE, AND GEOLOGIC RANGES

The isolation of spores and pollen in usable quantities requires special separation techniques, and magnifications far greater than those ordinarily employed by economic paleontologists are needed to identify the forms. Whereas most foraminifera can be determined by the use of magnifications of 50 diameters or less, spores commonly require more than 100 diameters. Figures 1 and 2 of Plate 1 show some typical spores and pollen. An appreciation of their size may be gained by noting the magnifications represented by these photographs.

Some indication of the possible quantitative abundance of plant fossils in ancient rocks is furnished by an examination of their abundance in modern sediments. Erdtman (1954) has shown that spores and pollen are accumulating in near-shore sediments off the coast of Sweden at a rate of 50,000 per square inch per year. Hoffmeister (see text-fig. 1) found as many

as 5000 spores and pollen grains per gram sample, 30 miles from shore in the Gulf of Mexico. Plant microfossils have been observed in abyssal sediments of the Mediterranean and have been collected almost all of the way across the Atlantic. Surely the productivity of plants and the carrying power of the wind have not been substantially different in much of the geologic past.

Spores have been reported from the early Paleozoic, but they are best known from the Pennsylvanian (Hoffmeister *et al.*, 1955). Pollen is associated with higher plants, and its occurrence begins with the Mesozoic. Kosanke (1950) and others who have used spores in their analyses of coal beds have demonstrated that even individual coal seams can be identified by these plant fossils. The zonation of other types of lithologic units is at present less precise; nevertheless, in certain areas, spores and pollen have proved to be as useful as foraminifera.

USES OF SPORES AND POLLEN

Foraminifera or other predominantly marine groups are well suited for use in subdividing and correlating marine deposits. There are a few foraminifera, some ostracodes, and occasionally other fossils that can be used in the study of brackish-water facies. Continental deposits, however, present a major problem, particularly where there is a considerable thickness of this type of sediment without interbedded marine strata. Spores and pollen, largely wind-blown, are not subject to the ecologic factors which restrict the distribution of water-deposited organisms (see text-fig. 2). They therefore form a potential stratigraphic bridge between marine, brackish-water, and nonmarine deposits, and offer possibilities for zoning the latter. As a typical example, it has been demonstrated in studies of Gulf Coast Tertiary sediments that an association of these fossils transgresses facies boundaries in the Frio formation of the Texas coastal plain, but that the zone of occurrence occupies a relatively constant stratigraphic position from the northern Gulf Coast to the Rio Grande.

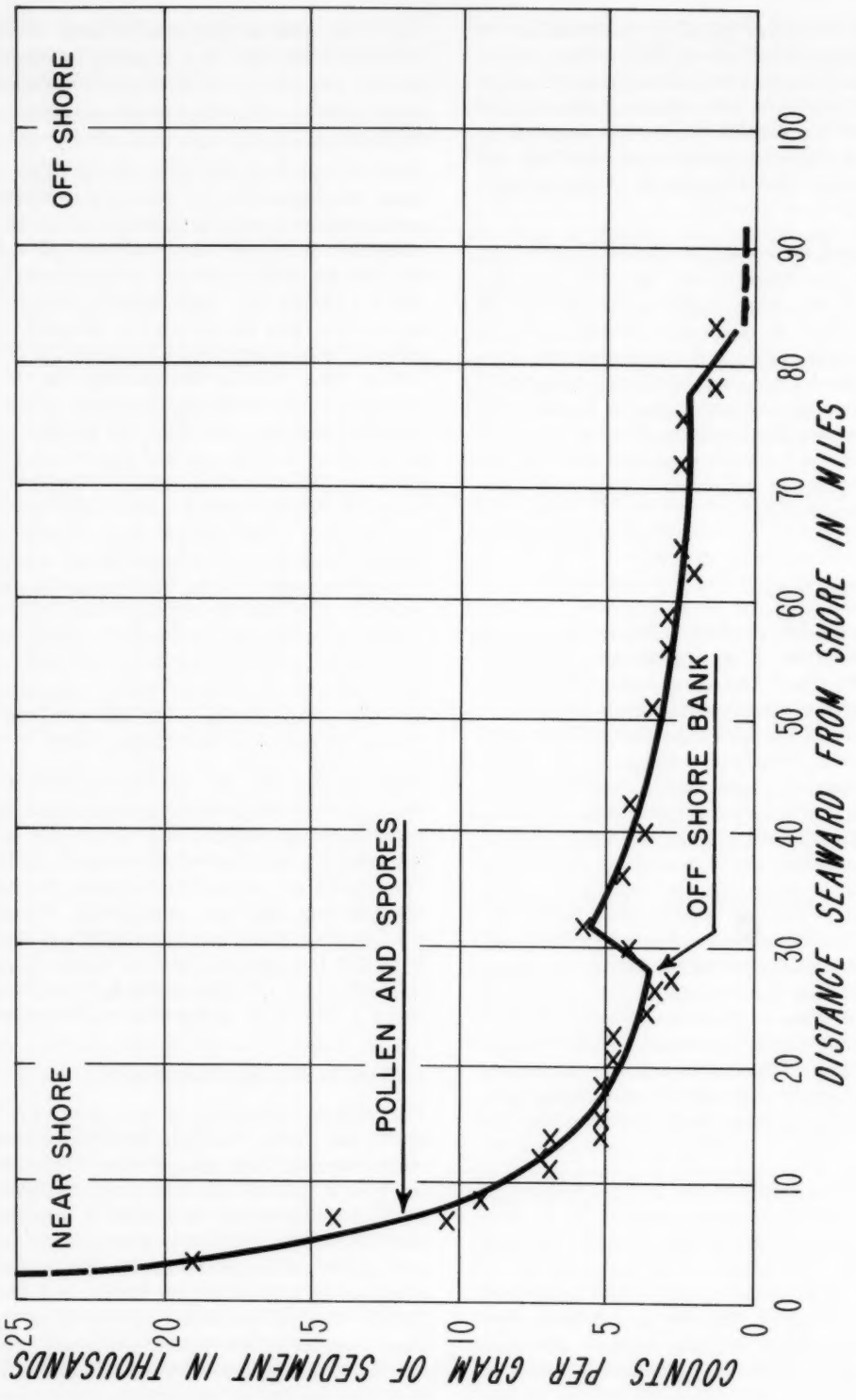
By the use of plant fossils it may, in time, be possible to resolve the paradox so aptly stated by M. K. Elias (1950), that some geographically widely separated stratigraphic units are believed to be contemporaneous because they carry different fossils, while other units are considered to be of different ages because they contain the same fossils. Dr. Elias referred, of course, to the relationship between faunas and environments, and to the migration of faunas in the course of geologic time, with the migration of their environments. Far more commonly than is perhaps recognized, this paradox has resulted in erroneous correlation. Wind-blown plant fossils may provide an answer to these enigmas.

Plant fossils can also be useful in the study of marine facies unfavorable to the growth and distribution of typical marine organisms. Salt deposits are an excellent example of this application. The principal salt beds in the Gulf province have been assigned both a Jurassic and a Permian age. *Cycadopites*, a Jurassic-Quaternary pollen, and *Leiosphaera*, a Mesozoic hystrichospherid, have already been reported by W. S. Hoffmeister from salt in the Humble Oil & Refining Company's No. 1 Emma Williams, Clark County, Alabama. Additional work on salt samples from other areas should help resolve this age problem. Attention has been called in several issues of The Micropaleontologist to similar research on salt beds in Europe and in Asia. Plant fossils may also more closely date stratigraphic units that carry long-ranging marine fossils. A recent example is the Morehouse formation, discovered in Union Producing Company's No. 1-A Tensas Delta, Morehouse Parish, Louisiana. The available animal fossils suggested only an Upper Paleozoic age (Imlay and Williams, 1943); diagnostic spores, however, placed the age as Middle to Upper Pennsylvanian (Hoffmeister and Staplin, 1954).

Many plant fossils are wind-blown and widely distributed; there are, however, certain forms which apparently are preserved relatively near or within the environment that favored the growth of the plants. Such forms are potential indicators of sedimentary environments, and may supplement interpretations from other criteria. An investigation of these possibilities in one area of the Gulf Coast is now being conducted by L. R. Wilson and A. E. LeBlanc as part of A.P.I. Project 51, on the study of Recent sediments.

OTHER POTENTIALLY USEFUL MICROFOSSILS

The principal emphasis in this paper has been on spores and pollen. No slight is intended, however, to other little-used fossil groups whose potentialities have not been fully explored. The hystrichospherids (pl. 1, fig. 3), for example, constitute a stratigraphically valuable group of organisms. The geologic importance of these members of the Protista has recently been discussed in some detail by Wilson and Hoffmeister (1955). The dinoflagellates (pl. 1, fig. 6), probably close relatives of the hystrichospherids, are another interesting group, but their stratigraphic distribution is poorly known at present. Bramlette and Riedel



TEXT-FIGURE 1

ABUNDANCE IN SEDIMENTARY ENVIRONMENTS

TEXT-FIGURE 2

FOSSIL OCCURRENCES IN SEDIMENTARY FACIES

(1954) recently pointed out the stratigraphic value of discoasterids (pl. 1, fig. 4), and Wilson and Hoffmeister (1952) have called attention to very minute foraminifera which they have called "microforaminifera" (pl. 1, fig. 5). The fresh-water alga *Pediastrum* is both an environmental indicator and a possible index fossil; representatives of this form have been noted in several parts of the world (Borge and Erdtman, 1954; Wilson and Hoffmeister, 1953). Another fossil group that could also be used more extensively in stratigraphic work is the Tintinnina. They are protozoans that have been used in Cuba, Mexico, Europe, North Africa, and elsewhere in zoning the Upper Jurassic and Lower Cretaceous. Judged by the number of papers that have appeared in the Journal of Paleontology, interest in these forms among American workers is practically nonexistent. Perhaps the excellent analysis by A. S. Campbell in Part D of the Treatise on Invertebrate Paleontology will rectify this neglect. A recent paper by Bronnimann (1955) called attention to still another useful microfossil, the bottle-shaped *Nannoconus* of uncertain affinities, which he has found useful in the zonation of the Lower Cretaceous and Upper Jurassic of Cuba.

ECONOMIC PALEONTOLOGY AND NOMENCLATURE

Economic paleontologists who use plant and other "new" microfossils in the solution of their stratigraphic problems are in a better position today to evaluate these fossils than were their predecessors who began work with foraminifera more than thirty-five years ago. Much more is known today about facies and environments of deposition, and, as C. C. Church pointed out in his 1953 presidential address to the American Association of Petroleum Geologists, there is greater consciousness and understanding of these factors among paleontologists. There is more of a tendency to emphasize the interpretative significance of fossil groups, but less tendency to expend so much energy on taxonomy; and this is indeed a healthy change. Correct taxonomy is essential to the rational progress of paleontology, but the nomenclatural "jungle" that has developed in the past four decades has been one of the chief deterrents to a free exchange of ideas among economic paleontologists. Many workers in this field do not have the time or the facilities to keep up with the changing "styles" in names and therefore refrain from contributing valuable stratigraphic information. W. L. Norem (1953) has issued a timely plea to avoid, in spore and pollen work, this nomenclatural pitfall which has plagued work with foraminifera. He has urged that "if fossil spores and pollen are to be brought into usefulness . . . a system of classification that is easy to use must be developed."

SUMMARY

Plant microfossils constitute one of the most significant of several new stratigraphic tools available to the oil industry. Investigations carried on in various universities and research centers throughout the world have been pointing the way, and several oil companies have now added staff members to use this tool. The usefulness already demonstrated in several areas suggests that in less than a decade these fossils will become a routine aid in stratigraphic work.

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EXPLANATION OF PLATE 1

1 Plant spores, × 700: a, *Punctati-sporites* sp.; b, *Convolutispora florida;* c, *Alati-sporites* sp.

2 Pollen, × 700: a, *Triorites* sp.; b, *Pinus* sp.; c, *Tricolpites* sp.; d, *Triporites* sp.

3 Hystrichospherids, × 700: a, *Hystrichosphaeridium* sp.; b, *Hystrichosphaeridium* cf. *H. trispinosum* Eisenack.

4 Discoasterids: a-b, × 1400.

5 Microforaminifera (megalospheric foraminifera): a-b, × 700.

6 Dinoflagellates, × 700: a, *Gonyaulax* sp.; b, *Eodinia* sp.

ABSTRACT: *X-ray and spectrographic analyses of a number of species of Recent and Pleistocene pelagic foraminifera from Caribbean, Atlantic and Pacific deep-sea cores indicate that the tests are made of virtually pure calcite, with only about 0.11% of strontium.*

Mineralogical and chemical composition of the tests of certain pelagic foraminifera

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Very little work has been done on the mineralogical and chemical composition of the tests of pelagic foraminifera. To the knowledge of the writer, only three X-ray analyses have been published. These show a calcitic structure for *Globorotalia menardii* (Mayer, 1932) and for *Globigerinoides rubra* and *Globorotalia tumida* (Switzer and Boucot, 1955). The few chemical analyses which have been published (Clarke and Wheeler, 1922; Revelle, 1944) show small amounts of Si, Al, Fe and Mg. Only the latter two may actually be contained in the calcite structure. The others may indicate sedimentary contamination, as it is impossible to wash specimens absolutely clean in preparation for analysis.

At the suggestion of the writer, X-ray and spectrographic analyses were made on a number of species of pelagic foraminifera by Dr. J. R. Goldsmith and Mr. O. Joensuu, respectively, of the Department of Geology, University of Chicago. The X-ray analyses followed a method for determining Mg in Ca positions in the calcite structure. Powder diffraction pictures were taken with North American Philips 114.19 mm. cameras using Fe radiation, as described by Goldsmith, Graf and Joensuu (1955). Back-reflections, highly sensitive to Mg content, were compared with a pure calcite standard. The spectrographic analyses were made with a 21-foot grating spectrograph (Jarrell-Ash Co.), using a technique which will be described elsewhere by Joensuu. These analyses are accurate to within $\pm 10\%$ of the determined values.

The foraminifera were obtained from deep-sea cores from the Caribbean Sea, the equatorial and North Atlantic Ocean, and the Pacific Ocean, kindly furnished by Professor H. Pettersson of the Oceanographic Institute of Göteborg, D. B. Ericson of the Lamont Geological Observatory, and Dr. G. Arrhenius of the Scripps Institution of Oceanography. The locations and depths of cores are given in Table 1. The prefix "A" identifies the Lamont cores. Cores distinguished by "A" or "B" following the core number are short pilot cores intended to sample superficial sediments. The cores have been described by Arrhenius (1952), Ericson (1953), and Phleger, Parker and Peirson (1953).

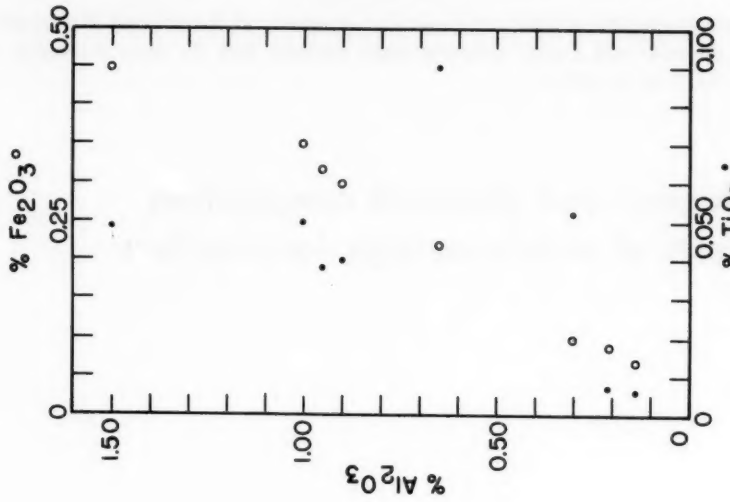
TABLE 1

LOCATIONS AND DEPTHS OF CORES

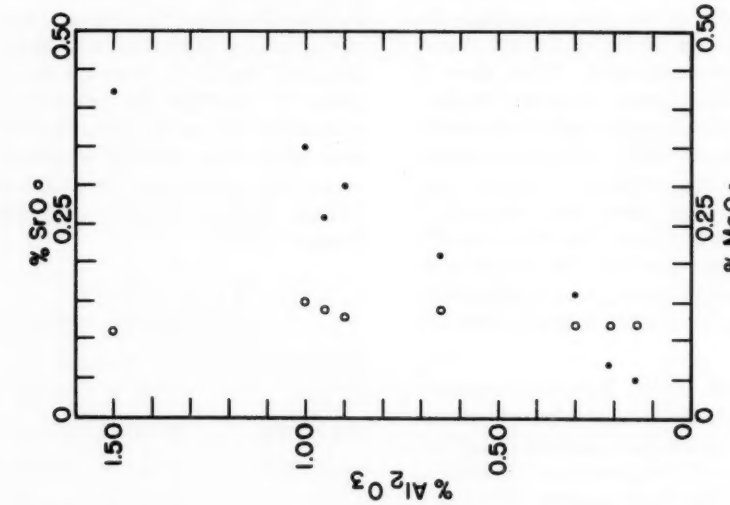
Core No.	Location	Depth (meters)
A179-4	13°36′ N. 74°48′ W.	2965
234A, 234	5°45′ N. 21°43′ W.	3577
246A, 246	0°48′ N. 31°28′ W.	3210
280A	34°57′ N. 44°16′ W.	4256
58B, 58	6°44′ N. 129°28′ W.	4440

Samples from the uppermost portions of the pilot cores and of core A179-4 are thought to represent essentially modern sediments, while the deeper samples represent Pleistocene sediments. Foraminifera belonging to different species were separated from each sample and crushed between glass slides, washed in distilled water in an agitator for one hour, and dried in an oven at 95° C.

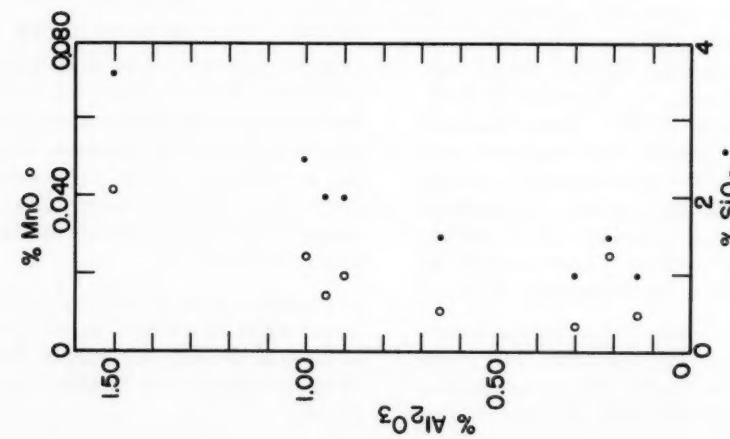
The results are listed in Table 2. Results of the X-ray analyses all indicate that the cell spacings are the same as those of virtually pure calcite. The presence of substituting cations was always beyond detectability ($<1\%$).



TEXT-FIGURE 3



TEXT-FIGURE 2



TEXT-FIGURE 1

TABLE 2

RESULTS OF THE SPECTROGRAPHIC AND X-RAY ANALYSES

Core No.	Depth below top (cm.)	Species	Spectrographic analyses (%)							X-rays (%) $MgCO_3$ $SrCO_3$ etc.
			TiO_2	Al_2O_3	SiO_2	Fe_2O_3	MnO	MgO	SrO	
A179-4	Top	*Globigerinoides sacculifera*	0.050	1.0	2.5	0.35	0.025	0.35	0.15	—
"	"	*Sphaeroidinella dehiscens*	—	—	—	—	—	—	—	<1
"	40	*Globigerinoides sacculifera*	0.040	0.90	2.0	0.30	0.020	0.30	0.13	—
"	240	*Globigerinoides sacculifera*	0.049	1.5	3.6	0.45	0.042	0.42	0.11	—
G-246A	0-1	*Globigerina dubia*	0.038	0.95	2.0	0.32	0.015	0.26	0.14	—
"	"	*Globigerinella aequilateralis*	—	—	—	—	—	—	—	<1
"	"	*Globigerinoides conglobata*	—	—	—	—	—	—	—	<1
"	"	*Globigerinoides sacculifera*	0.090	0.65	1.5	0.22	0.011	0.21	0.14	—
"	"	*Globorotalia menardii*	0.052	0.30	1.0	0.10	0.007	0.16	0.12	—
"	"	*Globorotalia tumida*	—	—	—	—	—	—	—	<1
"	"	*Orbulina universa*	—	—	—	—	—	—	—	<1
"	"	*Pulleniatina obliquiloculata*	—	—	—	—	—	—	—	<1
G-246	872-873.6	*Globigerinoides rubra*	—	—	—	—	—	—	—	<1
"	"	*Globigerinoides sacculifera*	—	—	—	—	—	—	—	<1
"	"	*Globorotalia menardii*	—	—	—	—	—	—	—	<1
"	"	*Pulleniatina obliquiloculata*	—	—	—	—	—	—	—	<1
G-280A	2-3	*Globorotalia menardii*	—	—	—	—	—	—	—	<1
G-58B	0-5	*Globigerina dubia*	—	—	—	—	—	—	—	<1
"	"	*Globorotalia tumida*	0.007	0.21	1.5	0.09	0.025	0.07	0.12	—
G-58	1-3	*Globorotalia tumida*	0.006	0.14	1.0	0.07	0.010	0.05	0.12	—

The spectrographic analyses indicate the presence of small amounts of several elements. The abundance of elements characteristic in terrigenous sediments (Ti, Al, Si) generally appears to be greatest in the Caribbean and least in the Pacific samples (Table 3). The Pacific samples may have washed more cleanly, or perhaps these elements are less abundant there than in the Caribbean and the Atlantic. In either case, analyses may be arranged in order of decreasing amounts of Al on the presumption that this indicates decreasing sedimentary contamination.

Table 4 shows that decreasing percentages of Al are paralleled by decreasing percentages of all other elements except Sr, which is nearly constant. This suggests that Sr is closely associated with the shell material, and probably substitutes for Ca in the calcite lattice.

If percentages of other elements are plotted against percentages of Al_2O_3 (text-figs. 1-3), Mg and Fe go to zero for zero Al_2O_3, but Si and Mn do not. Therefore, Mg and Fe probably are not associated with shell material, but small amounts of Si and Mn may be. Si cannot substitute for Ca, and how it might be associated with shell material is not clear. Mn can substitute for Ca. However, in the course of a study reported elsewhere (Emiliani, 1955), abundant incrustations of MnO_2 were observed on foraminiferal shells from certain levels of various deep-sea cores. Spectrographic analyses of heavily stained shells from the 450 cm. level of the Caribbean core A172-6 showed about 3% of MnO_2. These incrustations cannot be eliminated by simple washing in distilled water, and it is possible that a similar association obtains for the samples of Table 2, although no visible incrustations were observed under the microscope.

TABLE 3

RESULTS OF THE SPECTROGRAPHIC ANALYSES ARRANGED IN GEOGRAPHICAL ORDER

	Caribbean	Equatorial Atlantic	Equatorial Pacific
	%	%	%
TiO_2	0.050	0.090	0.007
	0.040	0.052	0.006
	0.049	0.038	
Average	0.045	0.060	0.007
Al_2O_3	1.0	0.65	0.21
	0.9	0.30	0.14
	1.5	0.95	
Average	1.1	0.62	0.17
SiO_2	2.5	1.5	1.5
	2.0	1.0	1.0
	3.6	2.0	
Average	2.7	1.5	1.2
Fe_2O_3	0.35	0.22	0.09
	0.30	0.10	0.07
	0.45	0.32	
Average	0.37	0.21	0.08
MnO	0.025	0.011	0.025
	0.020	0.007	0.010
	0.042	0.015	
Average	0.029	0.011	0.017
MgO	0.35	0.21	0.07
	0.30	0.16	0.05
	0.42	0.26	
Average	0.36	0.21	0.06
SrO	0.15	0.14	0.12
	0.13	0.12	0.12
	0.11	0.14	
Average	0.13	0.13	0.12

As far as Ti is concerned, wide variations may be observed superimposed on a general decrease with Al (text-fig. 3). This is probably a result of Ti being in different minerals from Al and reacting differently to washing.

Conclusions: Eleven species of pelagic formanifera, belonging to nine genera, were investigated: *Globigerina aequilateralis, Globigerina dubia, Globigerinoides conglobata, Globigerinoides rubra, Globigerinoides sacculifera, Globorotalia menardii, Globorotalia tumida, Orbulina universa, Pulleniatina obliquilocu-*

TABLE 4

RESULTS OF SPECTROGRAPHIC ANALYSES ARRANGED IN ORDER OF DECREASING PERCENTAGES OF Al_2O_3

Al_2O_3	TiO_2	SiO_2	Fe_2O_3	MnO	MgO	SrO
1.5	0.049	3.6	0.45	0.042	0.42	0.11
1.0	0.050	2.5	0.35	0.025	0.35	0.15
0.95	0.038	2.0	0.32	0.015	0.26	0.14
0.90	0.040	2.0	0.30	0.020	0.30	0.13
0.65	0.090	1.5	0.22	0.011	0.21	0.14
0.30	0.052	1.0	0.10	0.007	0.16	0.12
0.21	0.007	1.5	0.09	0.025	0.07	0.12
0.14	0.006	1.0	0.07	0.010	0.05	0.12

lata, and *Sphaeroidinella dehiscens.* The shell material of these species was found to be nearly pure calcite, with probably about 0.11% of Sr (= 0.13% of SrO) substituted for Ca in the calcite structure.

ACKNOWLEDGMENTS

The author is indebted to Dr. Goldsmith and Mr. Joensuu for the X-ray and spectrographic analyses, and for discussion of the subject matter. He is also indebted to Dr. J. Marvin Weller for having critically read the manuscript and substantially improved its style.

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notes and comment

Additions and corrections to "Geologic range of Paleozoic plant spores in North America"

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The ranges of several plant-spore genera in North America have been found to be longer than was known when the article entitled "Geologic range of Paleozoic plant spores in North America" (Hoffmeister, Staplin, and Malloy, 1955*a*) was published. The following corrections should be made on the range charts: *Alati-sporites,* Springer to Missouri; *Reinschospora,* Springer to Missouri; *Simozonotriletes,* Chester to Springer; and *Tripartites,* Chester to Springer.

The questioned occurrence of *Grandispora* in the Devonian should be deleted, and the genus limited to the Chester. The genera *Auroraspora, Convolutispora,* and *Grandispora* have now been published (Hoffmeister, Staplin, and Malloy, 1955*b*).

The following corrections should be made in the plate explanations:

Plate 1, figure 2, *Convolutispora;* figures 8, 10, new genus (in manuscript); figures 12-13, assignment to either *Apiculati-sporites* or *Cyclogranisporites* is questionable.

Plate 2, figure 6, *Convolutispora florida* Hoffmeister, Staplin, and Malloy, 1955; figure 8, *Tripartites vetustus* Schemel, 1950.

Plate 4, figure 19, *Florinites* sp.

Pustulatisporites Potonié and Kremp, 1954, was unintentionally omitted from the synopsis of genera used by Potonié and Kremp. Its characters are as follows:

Suite Apiculati. Spore wall bears scattered granules, warts or short cones. Genotype: *Pustulatisporites pustulatus* Potonié and Kremp, 1954. European range: Westphalian B + C.

In the legend at the top of Chart 3, *"Punctato-sporites"* should be corrected to read *"Punctata-sporites."*

DISCUSSION

Interest in the possibility of the existence of vascular plants during Cambrian time continues. The authors know of no undoubted vascular plant remains from pre-Silurian rocks. None has been isolated from the many preparations of Cambrian-Ordovician rocks of North America. E. C. Jeffrey, who furnished Darrah with the supposed Cambrian sample (Darrah, 1937) later found that the sample was not Cambrian in age (L. R. Wilson, personal communication). Most reports of Cambrian spores and vascular tissue come from areas where the structural and stratigraphic sequences are poorly known. Sinks and crevices in carbonate sequences may become filled with younger

rocks, and evaporite sequences are subject to solution and flowage. Channeling also causes difficulties in interpretation.

The article by Darrah is not the only one based on faulty material. A "core of soft crumbly gray mudstone" supposedly of Upper Devonian age was furnished to Radforth and McGregor (1954). The fossils which they illustrate include spores and pollen of Mesozoic age and spores of Carboniferous age. Dr. L. R. Wilson states that nine of the thirty-two illustrated fossils are Cretaceous types and that the remainder are Carboniferous. One (Radforth and McGregor, 1954, pl. 1, fig. 31) is a Cretaceous marine hystrichospherid. The authors have examined numerous Upper Devonian samples from seventy wells in west-central Alberta and have found none of the illustrated types present. They do occur, however, in the overlying Carboniferous and Cretaceous beds.

Several microfossils may be misinterpreted as vascular plant remains. These are *Leiosphaera* and other hystrichospherids (pre-Cambrian to Recent marine deposits), minute Ordovician Chitinozoa, and tissues of thalliform algae. The authors would be extremely interested in any vascular plant remains from undoubted Cambrian beds, or in angiosperm pollen from pre-Permian rocks, but they believe that the evidence is against the existence of these remains in rocks of these ages.

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The Palaeontological Society of India

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Bangalore, India

The Palaeontological Society of India, recently established with Dr. M. R. Sahni as first president, is dedicated to the advancement of the study of palaeontology and allied sciences in India. One of the main objects of the Society is to initiate and encourage palaeontological research throughout the country, with particular reference to its applications in petroleum exploration and coal prospecting. Particular attention will be paid to the study of human palaeontology in its relation to geochronology, based upon the study of Pleistocene cultures of India. The Society will endeavour to organise a permanent Field Survey for expeditions to selected areas to collect material for research on special topics of pure and applied palaeontology. An all-India palaeontological library and museum is also planned. In pursuing these objectives, the Society has been able to enlist the enthusiastic encouragement and cooperation of a number of eminent scientists both in India and abroad.

An important part of the Society's activities will be the publication of a journal containing authoritative papers on the pure and applied aspects of palaeontology and allied sciences in India. Professor L. Rama Rao of Bangalore, former Professor and Head of the Department of Geology in the University of Mysore, will be its Chief Editor. The inaugural number of the journal is in press and will be published shortly. It will contain more than 25 papers written by leading workers from India, the United Kingdom, the United States, Europe, South Africa, Ceylon, and Australia. Consequently, the journal will be of high standing and of international status.

The officers of the Society, drawn from various Indian universities, are as follows: President, Dr. M. R. Sahni (Calcutta); Vice-Presidents, Professor L. Rama Rao (Bangalore) and Professor Rajnath (Banaras); Secretary, Professor S. R. Narayana Rao (Lucknow), who served from January, 1950, until March, 1954, and Shri J. P. Srivastava (Lucknow), since April, 1954; Joint-Secretary, Shri B. S. Tewari (Lucknow); Treasurer, Dr. R. C. Misra (Lucknow); Council Members, Dr. M. R. Sahni (Calcutta), Dr. Rajnath (Banaras), Professor L. Rama Rao (Bangalore), Professor S. R. Narayana Rao (Lucknow), Dr. V. B. Shukla (Nagpur), Dr. R. C. Misra (Lucknow), Dr. G. W. Chiplonkar (Saugar), Shri Y. Nagappa (Digboi), Professor D. K. Chakravarthi (Banaras), Professor S. R. Kilpady (Nagpur), Dr. H. D. Sankalia (Poona), Dr. K. P. Rode (Udaipur), Shri B. B. Lal (New Delhi), Shri J. P. Srivastava (Lucknow), and Shri B. S. Tewari (Lucknow).

The editorial board of the journal consists of Professor L. Rama Rao, Chief Editor, and Dr. M. R. Sahni, Professor S. R. Narayana Rao, Dr. Rajnath, Shri B. B. Lal, and Professor D. K. Chakravarthi.

ARGENTINA

Since my last report of October, 1952, the following work has been going on in Argentina:

Foraminifera

Dr. H. Camacho, of the Instituto de Geología and the Dirección Nacional de Minería, has published a paper on two faunules of Upper Cretaceous age from wells in Comodoro Rivadavia, on the Atlantic coast of Patagonia (Cushman Found. Foram. Res., Contr., vol. 5, no. 1, pp. 31-35, pls. 5-6, 1954). Twenty-one species are described, sixteen of which are new. The author has related this fauna to the type Gulf Coast region of the United States.

During the past two summers, Dr. Camacho has taken part in Antarctic expeditions which have yielded numerous bottom samples as well as important geological, zoological and paleontological collections. Moreover, Dr. Camacho has carried on paleontological field work in the Comodoro Rivadavia region. Unfortunately, Dr. Camacho's studies at the Instituto de Geología were interrupted last year because the Institute was moving to a new building. His activities at the Dirección Nacional de Minería consist of routine work on macrofaunas of Tertiary marine deposits.

Dr. J. Frenguelli, of the Museo de Ciencias Naturales, Eva Perón, while doing microscopic work on samples of Quaternary deposits of peat moss from the Misión River, Rio Grande, Tierra del Fuego, discovered, among other microscopic remains of organic origin, two foraminiferal species. He assigned one of them to a new genus, *Auerinella*, which he established with *Auerinella fuegiae* as the genotype. Two papers presenting the results of these studies have been published (Acad. Sci. Fennicae, Ann., ser. A, no. 26, 60 pp., 1951, and no. 34, 52 pp., 7 tfs., 1953).

Your correspondent, of the Museo de Ciencias Naturales "B. Rivadavia," Buenos Aires, has studied foraminifera from Ensenadense (Pleistocene) and from Platense-Lujanense (Holocene), in the vicinity of Port Quequén, on the Atlantic coast. Thirty-two species were encountered in Ensenadense, and fifty-four in Platense-Lujanense. It is a dwarf fauna, and qualitatively corresponds almost exactly to the Recent fauna from the shore zone of the same region of Quequén described in a publication by your correspondent (Cushman Found. Foram. Res., Contr., vol. 6, no. 1, pp. 39-42, pl. 7, tf. 1, 1955). The results obtained so far on the Ensenadense and Platense-Lujanense material are too poor for publication. They should be augmented by the study of new material.

During the period reported, the activities of your correspondent with regard to foraminifera have consisted chiefly of studies of Recent forms from the Patagonian shelf. A study of bottom samples from the San Jorge Gulf and San Blas Bay has been completed, and papers concerning both regions have been published (Inst. Nac. Invest. Cienc. Nat., Rev., Geol., vol. 3, no. 3, pp. 79-228, pls. 1-19, and vol. 3, no. 4, pp. 247-300, pls. 20-29, 1954).

Laboratory studies of faunas in 123 bottom samples taken from the estuary of La Plata River have been completed as well. This region is especially interesting because it is characterized by exceptionally varied hydrological conditions, a natural consequence of the mixing of ocean waters with abundant masses of fresh water from the Paraná River. One hundred forty-four forms were encountered, of which 141 are benthonic and three are planktonic. This region, as well as the shelf regions mentioned above, is a zone in which *Buccella frigida* predominates. In comparison with the San Jorge Gulf and especially with San Blas Bay, the specimens here are of somewhat greater size and have more ornamentation. During these studies, a series of new problems arose that required the investigation of additional material from other shelf and coast regions. This was usually possible because of very effective collaboration with the Dirección General de Navigación e Hidrografía. Some ecological, zoogeographic, paleogeographic, and taxonomic conclusions have been reached, and these will be discussed in a paper now being prepared for publication.

Two other short papers on foraminifera, of a more general nature, were published by your correspondent during the period reported. One concerns the disintegration of type specimens preserved on glass slides or in glass tubes (Pal. Zeitschr., vol. 27, pp. 237-240, 1953), and the second is a discussion of the species and subspecies concepts in the classification of the foraminifera (Micropaleon-

tologist, vol. 8, no. 3, pp. 52-56, 1954).

Radiolaria

Dr. J. Frenguelli and Dr. H. A. Orlando, both of the Museo de Ciencias Naturales, Eva Perón, have started studies on Antarctic Radiolaria. A joint paper by these two authors, treating the very interesting and peculiar genus *Sticholonche*, is now in press.

Infusoria

Dr. J. Frenguelli is also studying the marine planktonic group Tintinnoinea in Antarctic material. Dr. R. A. Ringuelet, of the Museo de Ciencias Naturales, Eva Perón, has been studying marine representatives of the Heterotricha for the past several years. He has published two papers, one based on Antarctic collections and the other describing representatives of the same group found on the Argentine Atlantic coast (Univ. Nac. Eva Perón, Rev., new ser., Zool., vol. 7, pp. 215-255, pls. 1-6, 1953, and Univ. Nac. Eva Perón, Notas, vol. 16, Zool., no. 140, pp. 195-204, tfs. 1-13, 1953). In the first of these papers, Dr. Ringuelet described a new variety, and in the second, three new species.

Ostracoda

As indicated in my previous report, studies on Recent Ostracoda have been carried on by Dr. Ringuelet. Unfortunately, his studies on Infusoria, as well as other scientific research activities, have obliged this very active Argentine zoologist to stop his work on Ostracoda temporarily.

Dr. R. N. Bellen and Dr. S. J. Iglesias, of the Instituto de Geología y Minería, Jujuy, made an interesting collection of Ostracoda from the Petroliferous formation of northern Argentina, chiefly from the Province of Jujuy. The material collected is of great interest because the age of the deposits from which the samples were taken, the so-called Calcáreo dolomitico and Margas multicolores, is still the subject of a lively discussion, concerning whether they are Upper Cretaceous or Lower Tertiary. For the time being, the micropaleontological investigation of these deposits must be postponed because of the lack of necessary literature.

Cladocera

Dr. S. R. Olivier, of the Museo de Ciencias Naturales, Eva Perón, is engaged in a study of this very interesting group of organisms. During the investigation of a large amount of material, he discovered two marine species, *Podon polyphemoides* and *Evadna nordmanni*, and indicated the localities where these species had been found, on a map of the region (Univ. Nac. Eva Perón, Notas, vol. 17, Zool., no. 151, pp. 157-166, tfs. 1-3, 1954). As a result of limnological studies of the Laguna Salada Grande, Province of Buenos Aires, the same investigator described one new species of the genus *Moina* (Univ. Nac. Eva Perón, Notas, vol. 17, Zool., no. 148, pp. 81-86, tfs. 1-8, 1954).

In the summer of 1954-1955, Dr. Olivier collected a large number of samples of plankton from Lake Fagnano and Lake Escondido, Tierra del Fuego, and is now preparing a paper based on studies of the material collected. Dr. Olivier is also completing a paper on some Cladocera from Buenos Aires Province.

Microscopic elements of larger animal skeletons

Dr. Frenguelli, in one of his papers dealing with the microscopic study of samples from Tierra del Fuego, gives a brief description and drawings of sponge spicules found by him. Dr. Iglesias is continuing his work on the Ordovician conodonts of South America. His research has been temporarily interrupted by a lack of literature.

Diatoms

Dr. Frenguelli has been working actively for the past thirty-two years on the study of microscopic plants. In the Tierra del Fuego papers mentioned above, Dr. Frenguelli lists many diatoms identified by him, among them five new species and four new varieties.

Dr. D. A. Cappannini, of the Instituto de Suelos y Agrotecnica, has made a microscopic study of samples from seven sections of Quaternary age, and has published an interesting account of the geologic history of the area based on diatoms (Acad. Sci. Fennicae, Ann., ser. A, no. 41, pp. 1-63, 1954). The region is the one described by Frenguelli — Misión River, Rio Grande, Tierra del Fuego.

J. Perazzo, of the Museo de Ciencias Naturales "B. Rivadavia," Buenos

Aires, is continuing his study of Neogene diatoms from the Gobernación de Río Negro. His doctor's dissertation is based on this work.

Dr. Frenguelli has also studied freshwater diatoms from the Territorio Nacional de Misiones, among which he has found eight new species and twenty-three new varieties. The results of these studies have been published (Univ. Nac. Eva Perón, Rev., new ser., Bot., vol. 8, pp. 63-86, pls. 1-3, 1953). At present, Dr. Frenguelli and Dr. Orlando are studying diatoms of the Antarctic. The material is chiefly from the collections of Dr. Orlando, who took part in Antarctic expeditions during the past two summers.

Flagellata

Dr. Frenguelli is continuing his studies of the family Chrysostomataceae. In the papers already referred to, he gives a list of species determined by him, among which are one new species and one new variety. A special paper is also devoted to the study of Chrysostomataceae from Buenos Aires Province (Acta Geogr., no. 14, pp. 150-154, tfs. 1-16, 1955). In the latter paper, Dr. Frenguelli describes ten new species and one new variety. At the present time, Dr. Frenguelli is studying Flagellata from the Antarctic.

Dr. Cappannini, in his paper already referred to, also identified some members of the Chrysostomataceae.

Pollen

Dr. Orlando has completed and published a study on pollen from the Triassic of Mendoza (Univ. Nac. Eva Perón, Notas, vol. 17, Paleont., no. 101, pp. 147-156, tfs. 1-7). He is presently studying pollen from Tertiary coals.

ESTEBAN BOLTOVSKOY
Museo Argentino de Ciencias Naturales "B. Rivadavia"
Buenos Aires

ISRAEL

Z. REISS

A wealth of information has been gathered from routine analyses carried on by the Laboratory of Micropaleontology of the Geological Institute of Israel. This work has been done in connection with the search for underground water, oil and economic mineral deposits, as well as in connection with the mapping of the country. The information collected is of great help in the interpretation of the paleogeography of this region, to which we have lately been paying special attention. At present the biofacies of the late Cretaceous and early Tertiary deposits of this country, as indicated by the composition of microfaunas, are being investigated, as well as the connection between biofacies on the one hand, and lithofacies, chemistry of the rocks, and structure on the other.

Research on the stratigraphy of Jurassic and Lower to Middle Cretaceous deposits of this country is continuing, with the aid of microfacies methods. Special attention is being paid to various groups of foraminifera, as well as to other groups of microfossils, such as the calcareous algae, Ophiura, Holothuria, Bryozoa, and Ostracoda. Among the foraminifera, *Choffatella, Orbitolina* and various lituolids are important in the Lower Cretaceous; *Orbitolina, Cuneolina, Rotalipora* and *Globotruncana*, as well as various textularids, are important in the Cenomanian; and *Rotalipora, Globotruncana* and *Cuneolina* are important in the Turonian. As far as Jurassic faunas are concerned, the more important foraminiferal genera include *Valvulinella, Kurnubia, Trocholina* and various lituolids.

No foraminifera have been found as yet in strata of Triassic age in this country, but microscopic fragments of megafossils are of great value in the age determination of drill samples.

Your correspondent has started a detailed study on the taxonomy and phylogeny of the genus *Neoflabellina* in the late Cretaceous and early Tertiary of Israel. Two papers by your correspondent, dealing with the Cretaceous-Tertiary boundary in Israel and the Near East, are expected to appear in print during the first half of July. A paper on supposed fossil Phoronidea from Israel has been submitted for publication by M. Avnimelech.

Your correspondent will leave Israel later this year for a four-month trip to Europe, where he will study collections and methods in several micropaleontological laboratories.

Z. REISS
Laboratory of Micropaleontology
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PORTUGAL OVERSEAS

ARMENIO T. ROCHA

There are still a very limited number of micropaleontologists working in the Portuguese Overseas Provinces.

Portuguese Guinea

In the Boletim Cultural da Guiné Portuguesa, no. 27 (1952), Estela de Sousa e Silva published two papers: *Diatomáceas e dinoflagelados das águas litorais da Guiné Portuguesa,* and *Tintinnoinea das águas litorais da Guiné Portuguesa.*

Cape Verde Islands

Dr. J. Martins Ferreira and your correspondent are carrying on studies of samples of sediments collected from the islands of Santo Antão, Santa Luzia and Sal.

Angola (Portuguese West Africa)

Dr. J. Martins Ferreira and your correspondent are continuing work on the microforaminifera of the Tertiary in the environs of Luanda.

Mozambique (Portuguese East Africa)

In this province, the following persons are engaged in microzoological and microbotanical work: At the Centro Investigacão Científica Algodoeiro (C.I.C.A.), Engineer A. da Silva Teixeira and Professor Dr. Aurélio Quintanilha; at the Reparticão Técnica de Agricultura, Engineer Raimundo del Valle y March, Dr. Orlando Mendes, Engineer Tomás de Carvalho, and Engineer Dr. J. Alfaro Cardoso; at the Reparticão Técnica de Veterinária e Indústria Animal, Dr. Ernesto Ferreira de Abreu, Dr. F. Garcia Valadão, and Dr. Nuno Gago da Câmara; and at the Hospital Central Miguel Bombarda, Dr. Alberto Soeiro, Dr. Mário de Andrade, Dr. M. Andrade e Silva, and Dr. Jaime Travassos Santos Dias.

ARMENIO T. ROCHA
Lisbon

UNITED STATES — GULF COAST

STUART A. LEVINSON

Louisiana State University

Dr. Robert Treadwell's Ph.D. dissertation, completed last June, includes an extensive chapter on the ecology of the foraminifera and mollusks of the St. Bernard delta area of Louisiana. The complete dissertation will appear shortly as a technical report of the Office of Naval Research, Coastal Studies Institute.

Tetsuro Hanai is completing a report on *Leptocythere* and related ostracod genera from Tertiary and Recent sediments of Japan. Professor Allan Cheetham is continuing his studies of Upper Eocene Bryozoa of the Florida Peninsula, and the results of this study will appear shortly.

A handbook of ostracod taxonomy, by Henry V. Howe, has recently been published by the Louisiana State University Press:

HOWE, H. V., *Handbook of ostracod taxonomy.* Louisiana State Univ., Studies, Baton Rouge, La., 1955, Sci. Ser., no. 1, pp. 1-386. Paper cover. Price $5.00.

The handbook brings together, for the first time, the available data on the generic and suprageneric taxonomy of ostracods, both fossil and living forms.

The first part of the handbook lists described ostracod genera and suprageneric categories, both fossil and living. References to misspellings of generic names and suprageneric categories are included, with their equivalent names, *nomina nuda,* homonyms, and synonyms. Following the generic name is the type species, author, date, page reference to the original generic description, synonymy (where synonymy was suggested, with a notation of the author and reference), family affiliations and author (where a genus has been assigned to more than one family, this also has been noted), and the stratigraphic and geographic occurrence as given by the original author, or the age assigned to the type species in cases where the type species was described by an earlier author. Invalid generic names and suprageneric categories are underlined.

The second part of the handbook is an annotated bibliography of papers in which new genera and suprageneric categories are described, as well as other papers referred to in the first part of the handbook. It is the most complete bibliography on ostracod taxonomy ever to be published.

The third part of the handbook consists of a list of the serial publications containing works on ostacod taxonomy, giving the titles as they are listed in the Union List of Serials. If they do not appear in the Union List, they conform with standard library listings. With each serial publication is given a list of authors of articles on taxonomy, with dates of publication in the serial. This provides ostracod workers with a guide to the importance of the various journals. Appended to the handbook are additional entries from seven papers which were recently received by the author.

A handbook of this type, bringing together information on the taxonomy of ostracods, has long been needed. Dr. Howe has found that many of the reference dates have been consistently incorrect, as have the spellings of some generic names. A number of homonyms are noted for the first time in the handbook, but, because it is an objective study, no new names are proposed. There are a few typographic errors, and in some cases invalid names in Part 1 are not underlined; however, such errors are few in number.

This handbook will be a great help in correcting and standardizing taxonomy of ostracod genera and suprageneric categories, and to bring little-known genera to the attention of ostracod workers. As it stands, it should be an invaluable aid to the student as a reference to pages and figures of original descriptions and as a compilation of synonymy, and, because it is so comprehensive, it should stimulate research on the Ostracoda.

University of Mississippi

Dr. Robert Shaver is completing work on the ostracod families Healdiidae and Bairdiidae for the Treatise on Invertebrate Paleontology.

University of Houston

Dr. P. H. Southerland has joined the faculty of the University of Houston and is teaching a one-semester course in micropaleontology. Mrs. Gene Ross Kellough is working on the foraminifera of the Kincaid (lower Midway) of northeastern Texas for her master's thesis. This work is based on stratigraphic data from shallow borings and is primarily a detailed ecological study.

University of Texas

Charles B. Morris has completed a master's thesis on the foraminifera of the Del Rio shale of southern Texas. Mr. Morris examined a number of measured sections, including some complete cores in the southern Texas area, in addition to the type locality of the Del Rio shale. Illustrations of all species noted in this study are included in the thesis, as well as stratigraphic charts showing the ranges of the species.

Stanley Jaroska has completed a master's thesis on a statistical study of the foraminifera of the Del Rio shale of southern Texas. This investigation is a census study based on the number of specimens and on the species found per gram of original rock of the Del Rio shale in southern Texas. One of the major contributions of this study is a map showing a tentative boundary between open-sea conditions to the east and shallow-water neritic conditions to the west and to the north.

Professor Samuel P. Ellison is investigating the Devonian conodonts of the Rocky Mountain area. This investigation will involve stratigraphic and paleontologic studies in western Texas, New Mexico, Colorado, Wyoming, and Montana. Professor Ellison, chairman of the Geology Department, writes that he is expecting a number of additional graduate students in micropaleontology during the coming year.

Southern Methodist University

Professor Claude C. Albritton is studying some foraminifera from the Trinity and Fredericksburg groups (Lower Cretaceous) of the Finlay Mountains of trans-Pecos Texas. Albritton expects that this project will be completed in the near future.

Other news

The Dallas Geological Society is preparing to publish a symposium on the geology of Dallas County, Texas. Several papers pertaining to micropaleontology will be included in this publication. These papers will be based principally on the collections of the S.M.U. Museum, and the contributors will include Dr. C. I. Alexander of Magnolia Petroleum (Dallas), Dr. C. L. McNulty of Continental Oil (Roswell), William W. Schell of Sun Oil (Corpus Christi), and Robert F. Perkins of Southern Methodist University.

During the annual meeting of the Gulf Coast Association of Geological Societies in Biloxi, Mississippi, October 12-14, 1955, the following papers will be presented under the auspices of the Gulf Coast Section of the Society of Economic Paleontologists and Mineralogists: "The use of paleoecology in the Gulf Coast," by Robert Crouch; "Paleontologist or geologist," by A. D. Ellis; and "The Harang and related shales," by David Pope. This year the Gulf Coast S.E.P.M. has been concentrating on two projects: (1) To improve the quality and quantity of well cuttings received from sample-cutting laboratories. This project is being conducted by a committee under the direction of Frank Westmoreland of Houston, Texas. (2) To describe type localities, giving accurate directions for reaching them, and including columnar sections, photographs, and sketches. This work is being conducted under the chairmanship of E. H. Rainwater of Jackson, Mississippi.

Paul R. Beach has resigned from the Atlantic Refining Company in Lake Charles and is now paleontologist with Standard Oil of Texas in Houston. Ray Bane, formerly paleontologist with Union Oil of California in Houston, has resigned and is now with Placid Oil Company in New Orleans. R. E. Hohman, with the Union Oil of California in Tyler, has been transferred to Union's paleontologic laboratory in Houston. Dr. Morton P. Stephenson, formerly at Stanolind's paleontological laboratory in Houston, has been transferred to Stanolind's Tulsa, Oklahoma, office. Ray Artusy is joining the faculty of Texas Christian University. He is completing his doctor's dissertation at Louisiana State University, on a study of the ostracods from the Cook Mountain (Middle Eocene) of the Gulf Coast area.

STUART A. LEVINSON
Humble Oil & Refining Company
Houston, Texas

WEST INDIES

PAUL BRONNIMANN

Trinidad

The geological laboratory of Dominion Oil Company in Port-of-Spain has been enlarged. H. W. Kaska is now assisted by L. Martin and Howard Stacy, who resigned from his position with The Texas Company in New Orleans in January, 1954. Stacy is especially interested in ostracodes, and is investigating some of the rich ostracode faunas of the island.

No personnel changes are reported for the other companies in Trinidad. A. Wirz, micropaleontologist with Trinidad Petroleum Development Ltd., is engaged in an analysis of the planktonic foraminifera of a new subsurface formation of Albian to Cenomanian age. W. A. van den Bold, of United British Oilfields of Trinidad Ltd., has started a study of Trinidad ostracodes. The results of this study will be published in H. G. Kugler's treatise on the geology of Trinidad. H. Bolli is working on the planktonic foraminifera of the Cipero formation.

The first volume of the reports of the Orinoco Shelf Expedition to study Recent sediments in the Gulf of Paria appeared in 1954 in the Verhandelingen der Koninklijke Nederlandse Akademie van Wetenschappen, Afd. Natuurkunde (ser. 1, vol. 20, no. 5, pp. 1-245). In this volume, Tj. van Andel, H. Postma and others reported on the results of hydrographic, sedimentary and faunistic studies carried on by a Dutch group from 1952 to 1953 in the Gulf of Paria, between Trinidad and the Orinoco delta. Although this is essentially a sedimentary study, the dominant macrofaunas and benthonic microfaunas are also briefly discussed systematically and with respect to their geographic distribution. Brackish to marine conditions with wide salinity ranges now prevail in most parts of the Gulf. However, most of the dead macrofaunal associations collected in the Gulf indicate a marine environment. This fact, together with the virtual absence of living individuals, the bleached and transported aspect of the shells, and the presence of a dead coral fauna near Port-of-Spain, suggests that the macrofauna in the Gulf of Paria belongs to a period in which marine conditions persisted throughout the year. It is assumed that the rather sudden deflection of a large part of the Orinoco River water through the Boca Vagre estuary caused the death of the marine fauna in the Gulf of Paria. The time of the catastrophe has been determined by radiocarbon dating of the coral debris near Port-of-Spain as approximately 700 years ago.

Living foraminifera were found at only one station, and caution must therefore be observed in interpreting the distribution of microfaunal associations by ecologic factors. No microfaunas were found along the shore of the Orinoco delta, but your correspondent doubts that there is a zone devoid of microfauna along the coast of Trinidad, as shown in the distribution chart of the microfaunal associations. Four different foraminiferal associations are distinguished. The main factors which influence their composition are believed to be: (1) increase in salt content with depth; (2) decrease of temperature with depth; (3) seasonal variations in salt content and temperature; and (4) type of sediment. Thirty-eight foraminiferal species and thirty-seven ostracodes are described and figured.

A faunal paper on the foraminifera of the Gulf of Paria, by Ruth Todd and Paul Bronnimann, is nearing completion.

Barbados

Peter Ronai has been transferred to Cuba, and micropaleontologic work for Barbados is now done by the laboratory of the Cuban Gulf Oil Company in Havana.

Cuba

Gulf still maintains the only micropaleontologic laboratory in Cuba. No changes in personnel have been made since the last report in The Micropaleontologist. The current drilling activity in Cuba has made necessary the handling of more subsurface samples. Samples are also being received from Jamaica, Puerto Rico, and the southern United States. P. J. Bermúdez spent parts of December, 1954, and January, 1955, in Havana discussing plans with your correspondent for a monographic study of planktonic foraminifera. N. K. Brown, Jr., is making a detailed investigation of Cretaceous Gümbelinas and related forms. Paul Bronnimann has completed two papers on Pseudorbitoididae which will be published this year.

PAUL BRONNIMANN
Cuban Gulf Oil Company
Havana, Cuba

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